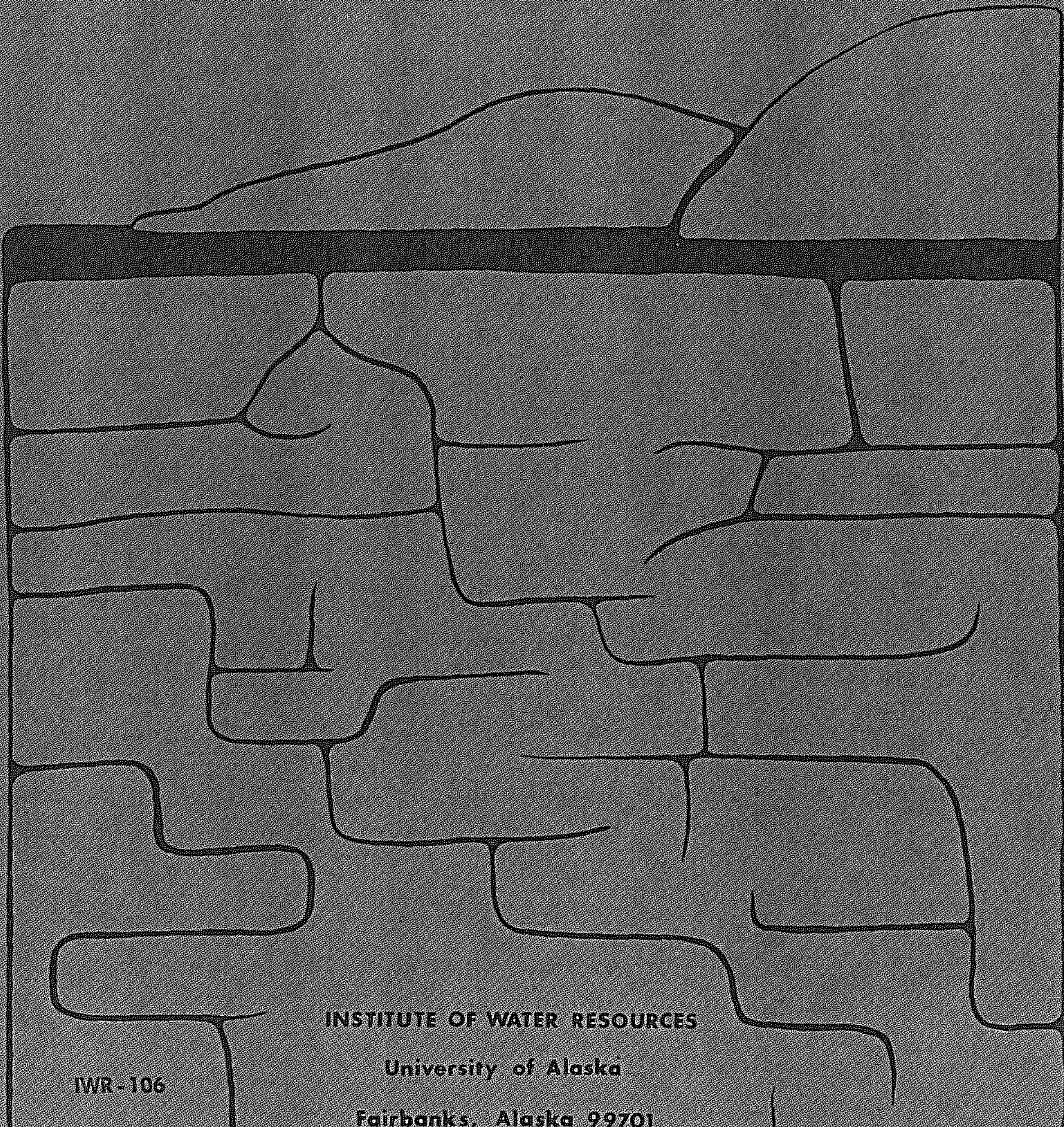
ALASKA'S WATER: A CRITICAL RESOURCE



INSTITUTE OF WATER RESOURCES

University of Alaska

Fairbanks, Alaska 99701

IWR-106

ALASKA'S WATER:

A CRITICAL RESOURCE

Alaska's Water: A Critical Resource
Stephen R. Bredthauer
American Water Resources Association

PROCEEDINGS

Stephen R. Bredthauer, Chairman
Alaska Section
American Water Resources Association

Institute of Water Resources
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Report IWR-106 November 1984

Bredthauer, S.R., Chairman. 1984. Alaska's water: a critical resource. Proceedings. Alaska Section, American Water Resources Association. Institute of Water Resources, University of Alaska, Fairbanks. Report IWR-106. 224 pp.

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INSTRUMENTATION

SOLAR AND LONGWAVE RADIATION DATA FOR SOUTH-CENTRAL ALASKA

J. H. Coffin[1]

ABSTRACT

Historical records of solar and longwave radiation measurements in Alaska are very sparse. This paper summarizes solar radiation and longwave radiation data collected for the Susitna Hydroelectric Project in south-central Alaska between 1980 and 1984. Solar radiation data were collected at seven different locations, and longwave measurements were made at one of the sites, all located in the Upper Susitna River Basin. In addition, both solar and longwave radiation data were recorded at another site - Eklutna Lake, near Anchorage.

Summarized data are presented and compared to other recorded data for the region, data-collection sites are described, instrumentation experience is reviewed, and several concerns pertinent to radiation measurement are identified. Potential problems due to condensation, frost, instrument inclination, and terrain effects are discussed.

Knowledge of basin-specific and regional radiation data is beneficial to hydrologists and water resource engineers for application in:

- snowmelt forecasts for flood analyses and water supply planning;
- computation of annual or seasonal energy balances of lakes, reservoirs, or frozen ground (permafrost)for limnological or geotechnical considerations;
- determinations of potential evapotranspiration from lakes and reservoirs used for water supply or hydroelectric generation; and
- assessments of energy availability for power generation (solar energy).

Additions to the historical data base are especially valuable in Alaska, where estimates must often be applied over large areas for which field measurements are not available.

INTRODUCTION

When the Alaska Power Authority in 1980 began its study of the feasibility of development of the Susitna Hydroelectric Project in south-central Alaska, practically no meteorological data had been obtained within the remote upper drainage basin. Measurement of local and regional climatic conditions was required for project design, for environmental analyses, and for documentation of existing climate. A network of six recording stations was installed to collect continuous data over the roughly 5000 square-mile area. In 1982, one of the

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original stations was discontinued and another initiated further downriver to support specific studies in that area. Also in 1982, an additional station was installed at Eklutna Lake to collect calibration data for Susitna reservoir-modelling efforts. R&M Consultants, Inc. was the subcontractor responsible for installation and maintenance of the stations and is still responsible for processing and reporting of current data.

This paper summarizes the measurements made of two parameters: solar and longwave radiation. The methods are described by which data were collected, how they were reduced, and how the present compilation was performed. The sites where each sensor was installed are also described. The data themselves are then presented in table form for each month of record and the monthly mean values compared between sites. Comparisons are also made to other radiation data that have been obtained in south-central Alaska and to theoretical maxima for each site. Finally, experience with the instrumentation is reviewed, and problems with which users of the data should be acquainted are discussed.

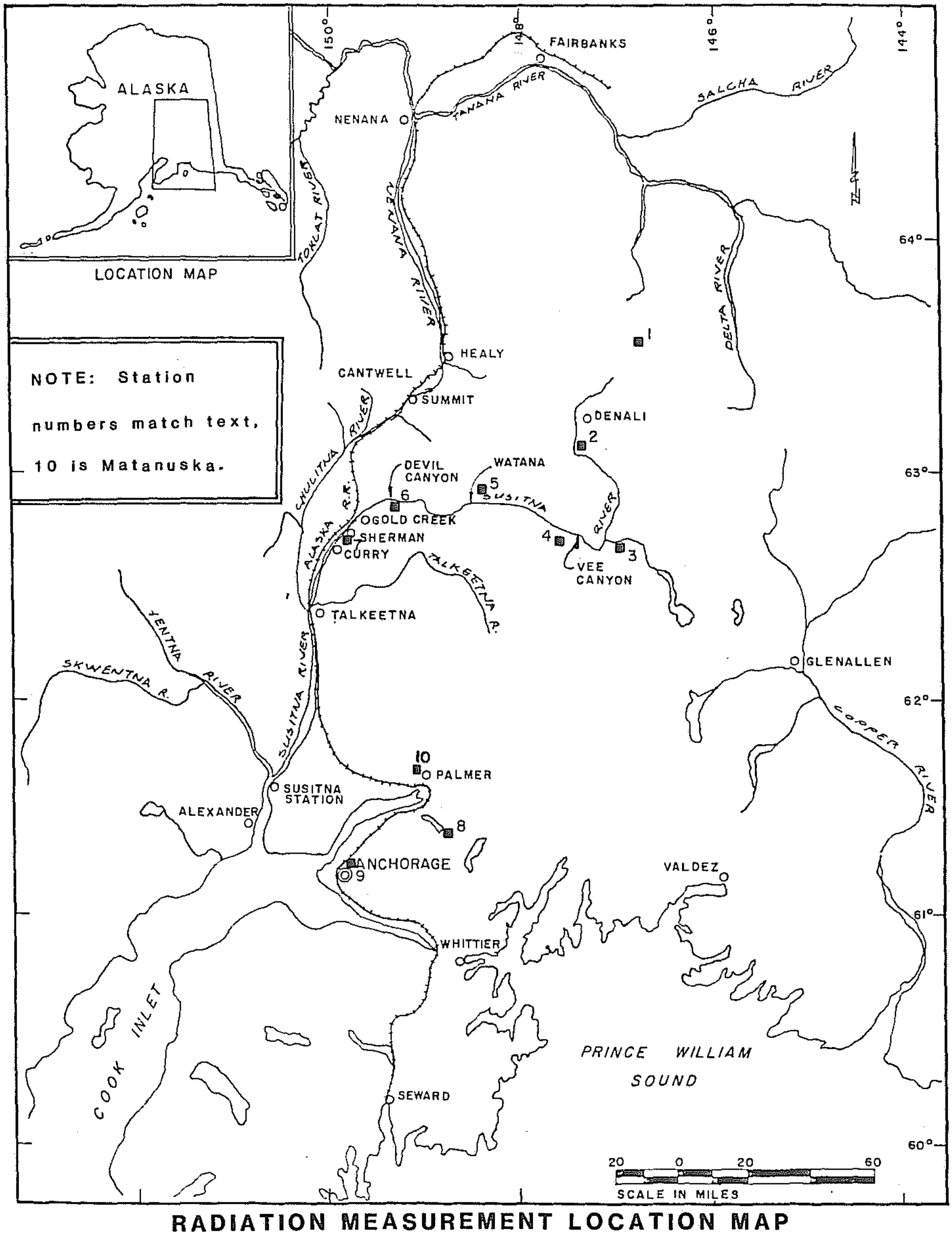
DATA COLLECTION SITES

The map in Figure 1 shows the ten sites reported herein where solar and longwave radiation data have been collected in south-central Alaska. Eight locations are stations which were installed for the Susitna Hydroelectric Project and are briefly described below. The other two are: Matanuska where data were collected between 1954 and 1975 and reported by Wise (1979), and Anchorage, where measurements were made between 1978 and 1982 and reported by Becker and Leslie (1983).

1. Glacier - The station sits on a southwest-facing ridge at approximately 4700 feet above sea level near the confluence of four major glaciers feeding the Susitna River mainstem. Several high mountains protrude above the horizon and offer shading at low sun angles in several directions. Snow and ice cover the surrounding area much of the year, increasing reflection of incoming solar radiation. The station latitude is 63°31' N.

2. Denali - This station is in an open tundra area on the high plateau south of the Alaska Range. It is at the Susitna Lodge, one mile east of the Denali Highway crossing of the Susitna River. The elevation is about 2700 feet, and the station latitude is 63°06' N. The Clearwater Mountains to the east of the site offer shading early in the day throughout the year.

3. Tyone - Situated on a narrow terrace between the Tyone River and an adjacent north-facing bluff, this station is near the southeast corner of the Upper Susitna River Basin and is at an elevation of about 2500 feet. The surrounding area is flat or gently rolling



RADIATION MEASUREMENT LOCATION MAP

FIGURE 1

with numerous lakes. The latitude at the station is 62°40' N. The Tyone station was discontinued in May 1982.

4. Kosina - The Kosina station sits atop a flat bluff within the tributary Kosina Creek drainage, approximately six miles south of the Susitna River. The station elevation is 2600 feet, and the latitude is 62°42' N. Mt. Watana (with a peak of 6255 feet) to the northwest of the site shades it late in the day through most of the year.

5. Watana - This station lies in a marshy area at 2300 feet elevation on the north side of the Susitna River near the Watana Damsite. No terrain features significantly protrude above the horizon to shade the sensor or the site. The latitude is 62°50' N.

6. Devil Canyon - The Devil Canyon station sits at 1500 feet elevation on a north-facing ridge close to the Susitna River near Devil Canyon damsite. The surrounding area is forested. The trees and north aspect both help to reduce the incident solar radiation at the site. The station's latitude is 62°49' N.

7. Sherman - This station is located in a grassy clearing on the floodplain of the Susitna River at 600 feet elevation and 62° 42' N latitude. The river is in a fairly deep, narrow valley at that point so hills on the northwest and southeast sides shade the site to some extent much of the year except at high sun angles.

8. Eklutna - The Eklutna station lies at the southeast end of seven-mile-long Eklutna Lake, thirty miles northeast of Anchorage. The station elevation is about 880 feet. The land at the site is flat but mountains several thousand feet high surround the station within three miles distance in several directions. The shortwave radiation readings are believed to be reduced and the longwave radiation readings increased by the high terrain. The station's latitude is 61° 21' N.

9. Anchorage - The Anchorage solar data were collected by the Arctic Environmental Information and Data Center (AEIDC) from the roof of their building in downtown Anchorage at an elevation of 107 feet and a latitude of 61°13' N. The site experienced some minor shading from a few trees and buildings in the area. Measurements were also made with pyranometers mounted south-facing vertically and south-facing inclined 61 degrees, but these are not addressed here.

METHODS

Equipment

The recording meteorologic stations selected for the project were Meteorology Research, Incorporated (MRI) Model 5112 digital weather stations, known as Weather Wizards. Each system has a microprocessor which records digital data onto magnetic cassette tapes at programmed intervals ranging from 5 to 60 minutes. A sampling interval of 15 minutes was used until October 1983, when the interval was changed to 30 minutes. Parameters measured at each site are air temperature, average wind speed and direction, relative humidity, precipitation, solar radiation intensity, and peak wind gust speed.

The solar radiation sensor supplied with each station is manufactured by Rho Sigma. The sensor is model RS1008, a photovoltaic pyranometer consisting of a light-sensitive silicon cell beneath an air-tight glass hemispherical dome. The sensor measures direct solar and diffused sky radiation, combined. The longwave radiation sensors used at the Watana and Eklutna stations were purchased from Eppley Laboratory Incorporated. Each is a model PIR precision infrared radiometer, also known as a pyrgeometer. It consists of a multi-junction thermopile beneath a silicon hemisphere.

Both types of radiation sensors are temperature-compensated, and both were installed horizontally, facing vertically upward. Each pyranometer was connected to an amplifier, Eppley model 450, which boosted the sensor output of roughly one millivolt to a signal in the range of 250 millovolts for input to the recorder. The amplifier required AC power, which was available at the Watana site (except in the winter of 1983-84), but the amp for Eklutna was rebuilt to operate from a DC power source.

Data cassette tapes were collected at approximately one-month intervals, at which time the sensors and recorder were inspected and maintained as necessary. The tapes were read in the office with a Memodyne model 3122 tape reader and the data stored on flexible disks using a Hewlett Packard 9845B computer. The computer program WIZWIZ, developed by R&M, was used to summarize the data, print tables, and draw graphical plots. Reported values of solar radiation were instantaneous measurements at 3-hour intervals and daily totals of insolation energy. Monthly data summaries have been prepared and are reported on a water-year basis for each station (R&M 1982a, R&M 1982b, R&M 1984a, R&M 1984b). It should be noted that the 1984 data have not been published yet and are preliminary; they are shown for comparison purposes.

Analysis

The monthly summaries presented in the annual water-year reports referenced above contain daily totals of solar energy received. Each day's value was computed by averaging all the instantaneous readings and applying the average over 24 hours. Summation of the daily values gave monthly totals, which are summarized in Table 1. The letters appended to several of the numbers indicate that estimates were required due to missing data in those months. Degrees of the data gaps are described in the table legend, but basically, lone numbers represent the most reliable measurements, followed by the "E" numbers,

TABLE 1 MEASURED MONTHLY SOLAR ENERGY TOTALS
(Kilowatt - Hours per Square Meter)

1. GLACIER

Month	80	81	82	83	84	Mean
January	-	2.7	6.3	6.6	3.6	5.3
February	-	21.4E	31.6	25.4	15.6E	23.5
March	-	72.5E	M	80.9	M	76.7
April	-	140.4M	143.5M	135.4	M	139.8
May	-	167.9E	193.9	M	213.2E	191.7
June	-	178.5	168.3	190.7E	201.3L	184.7
July	M	100.6	129.1	151.8	N/A	127.2
August	116.9E	102.1	122.7	111.3E	N/A	113.3
September	77.1	71.6	M	71.4E	N/A	73.4
October	37.4	34.4E	M	36.2	-	36.0
November	9.8E	12.6	9.6	13.7E	-	11.4
December	5.0	5.7	7.4	1.5	-	4.9

2. DENALI

Month	80	81	82	83	84	Mean
January	-	6.9	11.2	M	M	9.1
February	-	23.7E	30.7E	33.8E	M	29.4
March	-	76.4E	75.4E	83.9E	86.5	80.6
April	-	152.2E	139.2	147.2	150.7	147.3
May	-	152.0	174.1E	159.1	196.6	170.5
June	-	157.7	M	185.0E	184.8	175.8
July	140.6M	96.9	M	167.2E	N/A	134.9
August	99.9E	106.2	M	115.6E	N/A	107.2
September	M	67.6	M	69.8E	N/A	68.7
October	29.2M	37.9	M	N/A	-	33.6
November	9.9E	15.5	M	11.7	-	12.4
December	6.5	5.0	3.2M	M	-	4.9

3. TYONE

Month	80	81	82	83	84	Mean
January	-	M	15.6E	-	-	15.6
February	-	M	28.2	-	-	28.2
March	-	M	78.2	-	-	78.2
April	-	163.2E	156.2	-	-	159.7
May	-	157.8	187.8M	-	-	172.8
June	-	170.5	-	-	-	170.5
July	-	114.8	-	-	-	114.8
August	M	110.4	-	-	-	110.4
September	M	70.6	-	-	-	70.6
October	M	34.7	-	-	-	34.7
November	7.4M	13.6	-	-	-	10.5
December	M	2.6	-	-	-	2.6

4. KOSINA

Month	80	81	82	83	84	Mean
January	-	M	11.4E	10.9E	6.9E	9.7
February	-	76.5E	32.9E	30.9E	26.6E	41.7
March	-	M	80.3	86.1	93.8L	86.7
April	-	M	143.0	M	148.7L	145.9
May	-	M	183.4	132.8M	203.4M	173.2
June	-	135.3M	147.5	135.5M	M	139.4
July	-	100.6E	133.2	M	N/A	116.9
August	M	108.7	125.9	M	N/A	117.3
September	65.8	68.8	65.4E	M	N/A	66.7
October	25.4E	M	39.7	M	-	32.6
November	9.0	16.4	14.2	8.4	-	12.0
December	10.2E	M	5.8	6.0	-	7.3

5. WATANA

Month	80	81	82	83	84	Mean
January	-	M	8.0M	11.0E	7.1	8.7
February	-	16.6M	M	35.7E	26.7	26.3
March	-	83.2E	105.0M	92.5M	93.1	93.5
April	143.4E	159.1	143.3E	146.0E	153.2	149.0
May	147.4E	161.3	194.7E	168.9E	210.7	176.6
June	158.8M	170.6	164.5	184.3E	193.5	174.3
July	158.8E	115.7	150.6E	153.2M	N/A	144.6
August	M	111.6	147.1E	M	N/A	129.4
September	84.3M	78.0E	65.9E	M	N/A	76.1
October	M	39.9E	42.8M	34.0M	-	38.9
November	M	16.3M	14.4	16.8	-	15.8
December	M	6.7	4.7	8.3	-	6.6

6. DEVIL CANYON

Month	80	81	82	83	84	Mean
January	-	M	6.5	5.5E	M	6.0
February	-	M	16.0	16.1	M	16.0
March	-	59.8E	M	67.4	62.4	63.2
April	-	139.1E	134.1M	106.6	112.2	123.0
May	-	140.2E	149.4	136.7E	171.2	149.4
June	-	140.8E	129.8	146.7	148.8	141.5
July	148.8M	76.7	111.8	123.4	95.2	111.8
August	124.0M	M	112.1	88.6E	N/A	108.2
September	M	52.2M	44.3	54.7E	N/A	50.4
October	M	23.2E	17.7E	26.0E	-	22.3
November	M	4.1	4.9	5.7E	-	4.9
December	M	1.4	1.7	M	-	1.6

7. SHERMAN

Month	80	81	82	83	84	Mean
January	-	-	-	2.6M	2.7	2.6
February	-	-	-	M	14.6	14.6
March	-	-	-	95.5M	72.9	84.2
April	-	-	-	119.7	128.6	124.2
May	-	-	174.5M	163.7E	181.5	173.2
June	-	-	147.0	196.2M	170.5	171.2
July	-	-	142.3	143.4	N/A	142.9
August	-	-	132.2	109.0E	N/A	120.6
September	-	-	53.8	70.4	N/A	62.1
October	-	-	34.5E	37.5	-	36.0
November	-	-	M	13.0	-	13.0
December	-	-	3.5E	1.6	-	2.6

8. EKLUTNA

Month	80	81	82	83	84	Mean
January	-	-	-	10.5E	4.6	7.6
February	-	-	-	27.5M	22.8	25.1
March	-	-	-	105.1E	97.8	101.5
April	-	-	-	154.4	159.2E	156.8
May	-	-	-	194.1E	237.4	215.8
June	-	-	166.3M	M	229.0	197.7
July	-	-	M	M	169.9	169.9
August	-	-	M	M	150.2	150.2
September	-	-	75.9	87.0E	98.1	87.0
October	-	-	46.6	N/A	-	46.6
November	-	-	12.6	14.1E	-	13.4
December	-	-	7.2	1.7E	-	4.5

9. ANCHORAGE

Month	78	79	80	81	82	Mean
January	-	12.2	11.5	7.4	14.7	11.5
February	-	48.9	32.1	20.0	37.3	34.6
March	-	62.6	73.6	81.8	70.6	72.2
April	-	122.9	119.9	152.1	117.2	128.0
May	-	161.7	127.6	157.0	163.7	152.5
June	-	154.5	142.3	185.1	141.4	155.8
July	-	148.5	146.4	118.0	139.2	138.0
August	-	123.3	115.9	90.6	-	109.9
September	-	81.0	73.3	82.0	-	78.8
October	27.3	33.2	31.0	32.7	-	31.1
November	13.3	11.8	11.5	16.1	-	13.2
December	9.8	8.1	9.8	5.3	-	8.3

NOTE: See Table 2 for explanation of symbols used.

followed by the "M" numbers. Lone "M's" mean that too many days of the month were missing data to provide usable estimates. Values were not used for days for which any readings were missing.

The solar data in many months evidenced an offset, meaning that the readings were too high by a constant amount. Months where the reported midnight solar intensities were consistently non-zero were adjusted to take account of this effect. The typical magnitude of the offset is 240 W-H/m^2-day, or approximately 7 KWH per square meter per month.

The longwave summaries were also prepared by summing the daily values. Each day's value was computed as the average of eight 3-hour values. If less than eight were present for a day, the day's average was still used but the day was noted with an "M". The same rules from the table legend were then applied with regard to days with missing data. Data were not used if they appeared to be unreasonably erratic.

RESULTS - DATA COLLECTED

Monthly totals of recorded incident solar energy are presented in Table 1 for the eight Susitna Hydroelectric Project stations and for the AEIDC station in Anchorage. Table 2 gives the monthly totals of longwave energy measured at the Watana and Eklutna sites. Period-of-record means for each month of the year for the nine solar sites and also for Matanuska (adapted from Wise, 1979) are presented in Table 3 and also graphically in Figure 2. Several interesting trends are apparent in the tabulated and plotted data.

First, most evident in the plot is the timing of peak insolation for the year. It occurs in May at almost every station. The reason is probably less frequent cloud cover the past few years in May than in June. The exceptions are Denali, which tends to stay sunny generally in June; Anchorage, which is reported for a different period than the other stations; and Matanuska, which represents long-term average conditions. In this same vein, the July mean values are quite a bit lower than May's values (even though the summer solstice occurs closer to July), except at Matanuska. The reason is again felt to be weather conditions, recent July periods having had more cloud cover than days in May.

Another item worthy of note is the magnitude of the monthly values at Devil Canyon, which are consistently lower than at other stations, such as the nearby Watana station. As noted in the site descriptions, the Devil Canyon station is set on a north-facing ridge and also has trees around it - both of these factors probably contribute to the low measurements. Conversely, the values at Eklutna are consistently higher than at other sites. An explanation for this may be that the high local terrain increases the measured radiation by reflection.

The longwave radiation values are more uniform throughout the year than are the solar values, but they still peak during the summer when warmer

TABLE 2 MEASURED MONTHLY LONGWAVE RADIANT ENERGY
(Kilowatt - Hours per Square Meter)

	WATANA						EKLUTNA					
Month	80	81	82	83	84	Mean	80	81	82	83	84	Mean
January	-	-	-	154.8E	M	154.8	-	-	-	M	208.1	208.1
February	-	-	-	152.2	M	152.2	-	-	-	M	203.1	203.1
March	-	-	-	158.5E	M	158.5	-	-	-	M	217.9	217.9
April	-	-	-	181.4E	M	181.4	-	-	-	M	223.4	223.4
May	-	-	-	212.8M	284.8M	248.8	-	-	-	M	232.8M	232.8
June	-	-	-	205.2M	277.7	241.4	-	-	-	266.5M	260.7E	263.6
July	-	-	-	M	294.3E	294.3	-	-	-	274.2	275.8E	275.0
August	-	-	M	M	259.0E	259.0	-	-	M	262.1E	M	262.1
September	-	-	M	207.4M	227.4E	217.4	-	-	M	237.7	N/A	237.7
October	-	-	M	204.4M	-	204.4	-	-	M	229.0	-	229.0
November	-	-	168.5E	176.6	-	172.6	-	-	M	214.3E	-	214.3
December	-	-	169.0	M	-	169.0	-	-	190.0M	203.8E	-	196.9

Explanation of Symbols used in Tables 1 and 2

E Estimated value. E follows the monthly total if any readings for the period were missing, for up to 9 days. Monthly totals were computed by determining the average daily value for the good days of the record and then extrapolating to the full month.

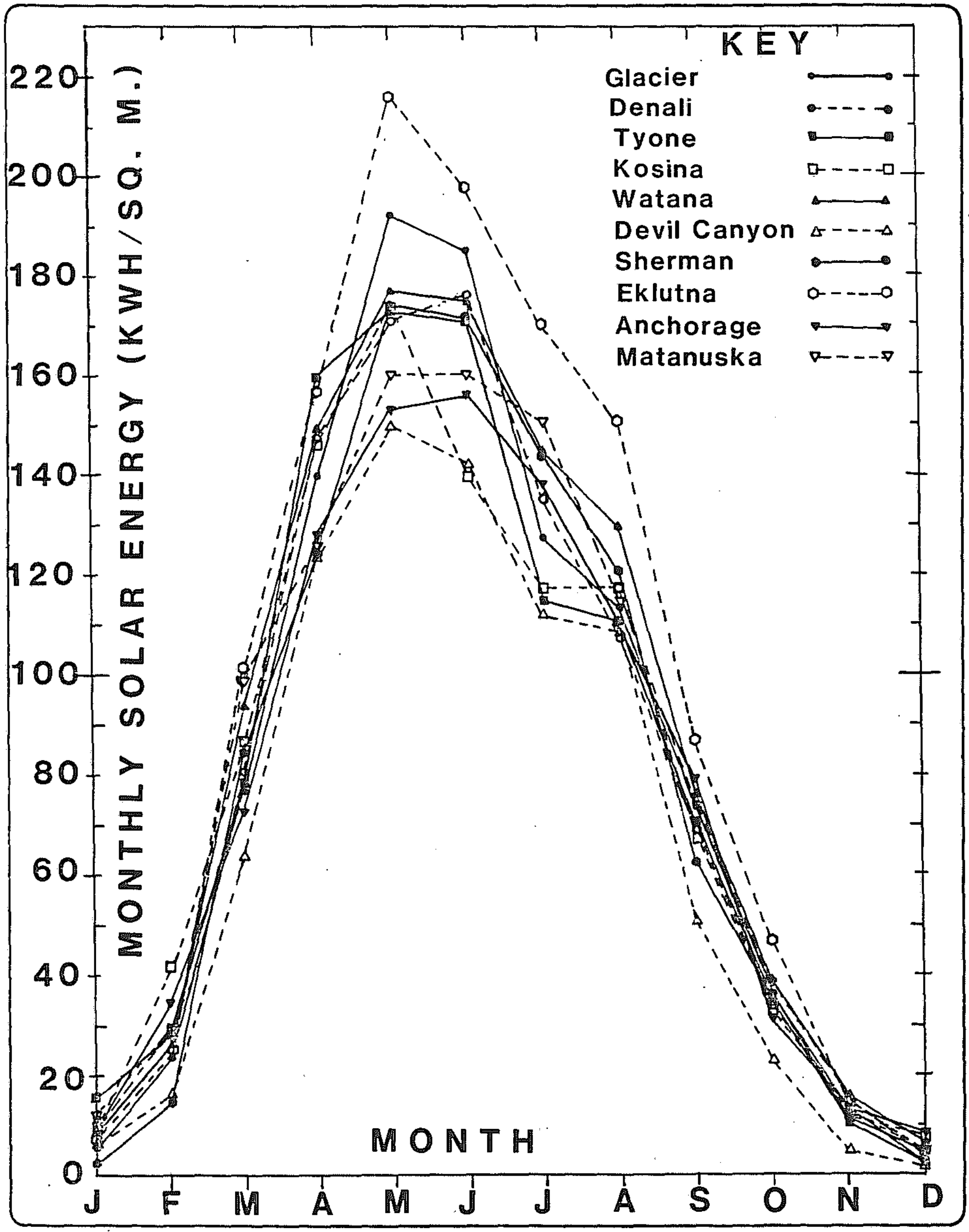
M Insufficient or partial data. M follows the monthly total if any readings for the period were missing on 10-20 days. Monthly totals were computed in the same manner as were the "E" months. If more than 20 days of the month are missing data, then M appears in place of the monthly value.

N/A Not available. Data were recorded but have not yet been reduced to a usable form for summary.

\- A dash indicates that no data were collected this month because the station was not installed (also used for months in 1984 which have not yet been completed).

TABLE 3 SUMMARY OF RADIATION DATA BY MONTH (KWH/sq m.)

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean Annual	# of Months Reported	Period of Record
SOLAR RADIATION															
Glacier	5.3	23.5	76.7	139.8	191.7	184.7	127.2	113.3	73.4	36.0	11.4	4.9	987.9	41	7/80 - Present
Denali	9.1	29.4	80.6	147.3	170.5	175.8	134.9	107.2	68.7	33.6	12.4	4.9	974.4	36	7/80 - Present
Tyone	15.6	28.2	78.2	159.7	172.8	170.5	114.8	110.4	70.6	34.7	10.5	2.6	968.6	15	8/80 - 5/82
Kosina	9.7	41.7	86.7	145.9	173.2	139.4	116.9	117.3	66.7	32.6	12.0	7.3	949.4	34	8/80 - Present
Watana	8.7	26.3	93.5	149.0	176.6	174.3	144.6	129.4	76.1	38.9	15.8	6.6	1039.8	44	4/80 - Present
Devil Canyon	6.0	16.0	63.2	123.0	149.4	141.5	111.8	108.2	50.4	22.3	4.9	1.6	798.3	38	7/80 - Present
Sherman	2.6	14.6	84.2	124.2	173.2	171.2	142.9	120.6	62.1	36.0	13.0	2.6	947.2	24	5/82 - Present
Eklutna	7.6	25.1	101.5	156.8	215.8	197.7	169.9	150.2	87.0	46.6	13.4	4.5	1176.1	22	6/82 - Present
Anchorage	11.5	34.6	72.2	128.0	152.5	155.8	138.0	109.9	78.8	31.1	13.2	8.3	933.9	50	10/78 - 7/82
Matanuska	11.9	29.6	98.4	125.6	159.7	159.8	150.3	113.9	72.6	37.8	14.6	4.7	978.9	253?	12/54 - 12/75
LONGWAVE															
Watana Longwave	154.8	152.2	158.5	181.4	248.8	241.4	294.3	259.0	217.4	204.4	172.6	169.0	2453.8	16	8/82 - Present
Eklutna Longwave	208.1	203.1	217.9	223.4	232.8	263.6	275.0	262.1	237.7	229.0	214.3	196.9	2763.9	15	8/82 - Present



DWN	JHC
CKD	
DATE	10/84
SCALE	

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Figure 2
Average Monthly Solar Energy Totals

F.B.	
GRID	
PROJ.NO	
DWG.NO	

atmospheric temperatures are present. The longwave quantities at both sites are significantly higher in every month than are the solar values, for an unknown reason. The Eklutna longwave values are higher than Watana's, probably due to the high mountains in close proximity to the Eklutna sensor.

DISCUSSION

The solar energy totals presented herein give a good indication of available incident energy on a monthly basis at several locations around south-central Alaska. Several differences between stations were noted, due to latitude, local weather conditions, local terrain effects, "environmental" influences (such as reflection from surrounding snow or terrain), or by instrument anomalies. This latter factor includes instrument inclination (i.e. not mounted horizontally), condensation or frost on the inside or the outside of the sensor dome, and differences in sensor calibration. These are all factors to consider during application of the data.

ACKNOWLEDGMENTS

The radiation data for the Susitna Hydroelectric Project were collected for the Alaska Power Authority under contract to Acres American (until February 1983) and Harza-Ebasco Susitna Joint Venture (after February 1983). The author is grateful to the Power Authority and to Harza-Ebasco for review comments and for permission to present the paper. The author is also grateful to James L. Wise, Alaska State Climatologist for assistance in researching other data sources.

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INSTRUMENTATION OF THE TIDE-AFFECTED POTTER MARSH OUTLET NEAR ANCHORAGE, ALASKA

by Timothy P. Brabets[1]

ABSTRACT

The lower end of Rabbit Creek, the outlet of Potter Marsh, is influenced by high tides (as great as 33 feet) on Cook Inlet. During these periods, backwater occurs in the marsh and water-quality variables change markedly. To collect the data needed to adequately describe water quality in the tide-affected part of the marsh, new instrumentation had to be evaluated. The Campbell Scientific CR21 micrologger[2], when used in combination with standard U.S. Geological Survey and other commercial instrumentation, allows the user to control automatic sediment samplers as well as other sensors such as water temperature and specific conductance as a function of water stage.

INTRODUCTION

The U.S. Geological Survey is involved in water resources studies throughout the state of Alaska. One such study deals with the hydrology of Potter Marsh, located along the New Seward Highway, approximately 10 mi south of downtown Anchorage (fig. 1).

The hydrologic characteristics of Rabbit Creek, at the outlet of Potter Marsh, are unique in that high tides (as great as 33 ft) on Cook Inlet create a flow of backwater into the marsh that markedly changes the water quality. To collect data required to adequately describe the rapid water-quality fluctuations in the tide-affected part of the marsh, advanced instrumentation had to be used. The purpose of this paper is to describe the instrumentation - both U.S. Geological Survey and commercial - currently installed at the Potter Marsh outlet.

DATA REQUIREMENTS AND INSTRUMENTATION

Hydrologic data currently being recorded at the Potter Marsh outlet include water stage, water temperature, and specific conductance of water. Water samples are collected at selected times and events (extreme high tides). Each of the data items could be collected separately by use of digital recorders, float switches, and event markers. However, this would make data collection cumbersome as well as making data analysis difficult. Thus, alternatives were chosen to make data collection easier, more efficient, and centrally processed. The following equipment was chosen:

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[1]Hydrologist, U.S. Geological Survey, Water Resources Division, 1209 Orca St., Anchorage, AK 99501.

[2]Use of brand names is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

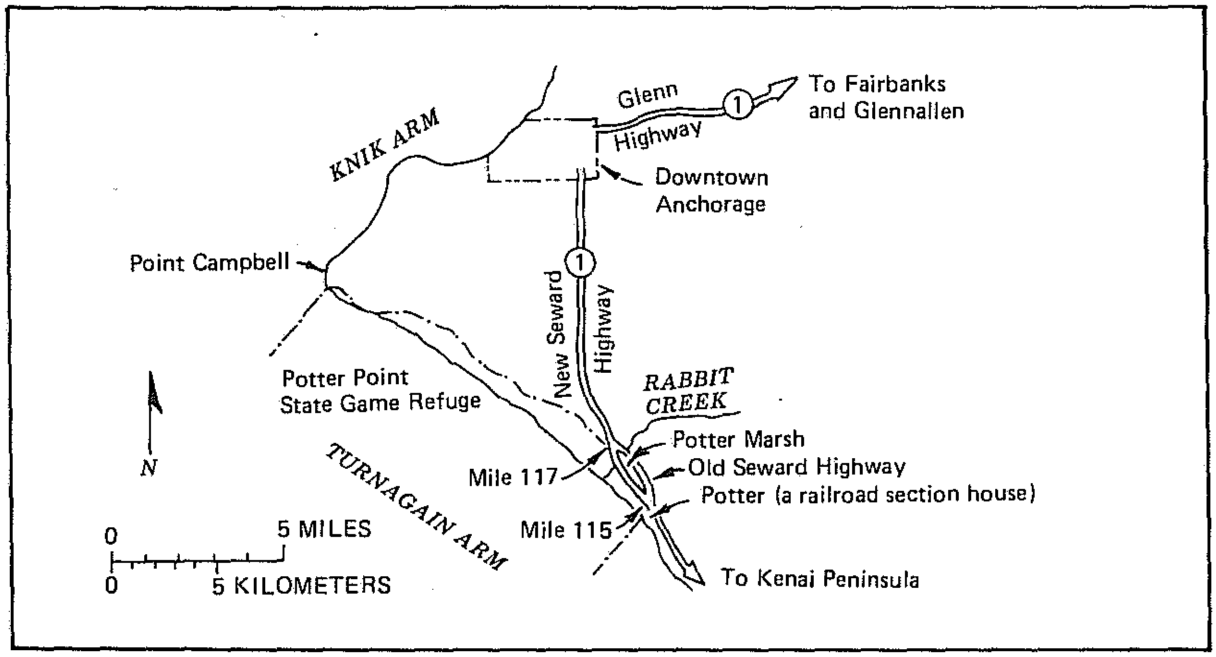

Figure 1.--Location of study area.

Schaevitz P-3000 Pressure Transducer - This transducer measures water stage and operates from an unregulated source of 10-32 DC volts to output a DC voltage ranging from 0-5 volts which is linearly proportional to applied pressures. Different pressures are applied depending on the pressure head of water above a fixed point (or orifice) in the stream. A CONOFLOW gas-purge system provides a means of transmitting the pressure head of water above the orifice to the transducer.

U.S. Geological Survey Mini-Monitor - The U.S. Geological Survey Mini-Monitor, which is operated by a 12-volt battery, is a system designed to measure up to four water-quality properties, which can include any combination of water temperature, specific conductance, pH, or dissolved oxygen. For the Potter Marsh study two parameters are being measured: water temperature, and specific conductance with ranges of 0 to 1,000, and 0 to 100,000 micromhos per centimeter at 25°C (umho/cm).

Manning Model S-4050 Automatic Water Sampler - The Manning S-4050 portable sampler is used to collect water samples. The sampler self-purges an intake line before and after each sampling interval to clear the intake line of obstructions and residue from the previous sample. A vacuum system creates sample transport velocity of 3 ft/s or better through the intake line composed of .375-in. inside diameter tubing. Up to 24 polypropylene bottles (500-mL size) can be filled. Power for the sampler is supplied by a 12-volt battery.

Campbell Scientific Inc. CR21 Micrologger - The 9-channel CR21 micrologger is a battery-powered microcomputer with a real time clock, a serial data interface and a programmable analog-to-digital converter. Once each 10 seconds the micrologger samples the input signals according to output programs selected from the user-entered output table. Data is then stored on either a Campbell Scientific storage module or a standard cassette tape. In addition, there are two binary inputs and four control outputs on the CR21 which are used with special programs for controlling external devices.

SENSOR INPUT CONNECTIONS AND INPUT PROGRAMMING

Instrument setup and other connections to the CR21 are as follows (fig.2):

Channel 1 - Water Stage (pressure transducer)
Channel 2 - Water Temperature (Mini-Monitor)
Channel 3 - Specific Conductance -- 0 to 1,000 umho/cm (Mini-Monitor)
Channel 4 - Specific Conductance -- 0 to 100,000 umho/cm (Mini-Monitor)

Connections are made from output port 1 to Campbell A21 relay and from the relay to the Manning Sampler. When a 5-volt pulse is sent from the output port to the relay, the Manning Sampler is activated. Similarly, connections are made from output port 2 to the Mini-Monitor, and when a 5-volt pulse is sent from this output port, the Mini-Monitor is activated. Finally, connections are made from binary input port 1 to a 12-volt relay and from the relay to the pump motor on the Manning Sampler. Each time the sampler is activated it presents a 12-volt level to the binary port. The CR21, in turn, then determines the sampler number accordingly.

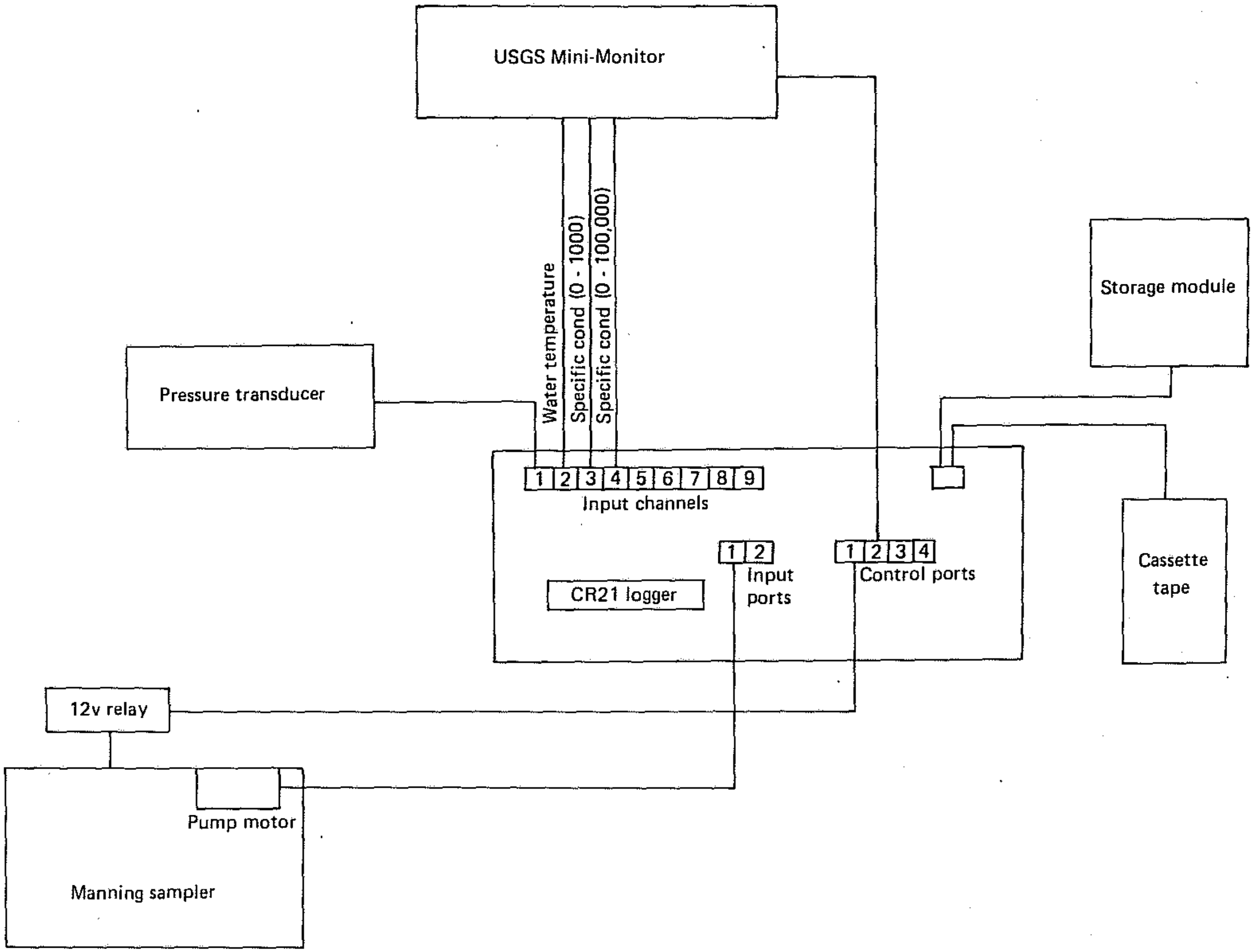

Figure 2.-- Schematic of instrument setup.

After all connections have been made the user enters input programs into the CR21. These programs specify the type of signal conditioning and analog-to-digital conversion to be done including linearization of selected input signals. A total of nine input programs can be entered with each program operating on a different channel of the recorder. The CR21 can measure volts, millivolts, AC and DC resistance, and pulse counts. For instance, output from the Mini-Monitor for water temperature is volts. Thus, the user programs the CR21 to 'read' voltage each time it scans channel 2. The CR21 will then convert the voltage into engineering units using the equation:

$$EU = aX + b$$

where EU is the value of the particular sensor, in engineering units;
a is the multiplier suppled by the user;
x is the voltage measured by the CR21;
b is the offset supplied by the user.

Two examples are given:

(1) For water temperature: a (the multiplier) = 25.0
b (the offset) = 0.0

The CR21 scans channel 2 (water temperature) and reads .465 volts. The CR21 now converts the voltage into the actual water temperature by using the equation EU = 25 (.465) + 0.0 = 11.62°C and stores this value.

(2) For specific conductance: a (the multiplier) = 434
b (the offset) = 4.69

The CR21 scans channel 3 (specific conductance) and reads .200 volts. The CR21 now converts the voltage into the actual specific conductance as follows: EU = 434 (.210) + 4.69 = 9.58 umho/cm.

The values of a and b for each sensor can be determined in a variety of ways. For these sensors, the values of a and b were initially set to 1 and 0 respectively. Then, for various water stages, water temperatures, and conductances, the various voltages were recorded. When a sufficient number of points was obtained, the values were plotted on graph paper and the coefficients determined.

OUTPUT PROGRAMMING

Up to three output tables can be programmed into the CR21 to process data. An output table is a set of numbers entered into the CR21 that specifies the output programs to be executed. The output programs are executed at time intervals programmed by the user and can range from 1 to 1440 minutes (1 day). Various outputs specified by the user can be given in each program. Examples include (but are not limited to) sensor value, average value of a sensor for a given period of time, maximum values, minimum values, and the water sampler control program. Because the water sampler control program is an integral part of the data-collection effort, a full explanation of its capabilities is necessary.

The water sampler control program was developed by Campbell Scientific Inc. for the Geological Survey. This program allows the user to activate two CR21 output ports and record the input channel values based upon the values of a specific channel, usually water stage. One port activates the Manning Sampler and one port activates the Mini-Monitor. The user must specify following inputs:

1) Water Stage Input Channel Number

2) Water Stage #1(H1) - At this water stage level the water sampler program will start.

3) Water Stage #2(H2) - At this water stage level the water sampler program will terminate.

4) Water Stage #3(H3) - At this water stage level the Manning Sampler will activate at the time interval specified by the user (T1).

5) Water Stage #4(H4) - At this water stage level the sampler will activate at a faster or slower interval (T2).

6) Hydrologic Time Interval - Time period in minutes at which data are recorded when the water sampler programs begins.

7) T1 - Time interval at which samples are to be taken by the Manning Sampler when water stage is above water stage #3(H3).

8) T2 - Time interval at which samples are to be taken by the Manning Sampler when water stage is above water stage #4(H4).

9) R-Differential rise - If the water stage changes R feet before the next sample is to be taken, the Manning Sampler will activate.

10) F-Differential fall - If the water stage falls F feet before the next sample is to be taken, the Manning Sampler activates.

11) Sampler Control Port - The designated CR21 output port which activates the Manning Sampler.

12) Auxiliary Control Port - The designated CR21 output port which activates the Mini-Monitor.

13) Auxiliary Input Channels - Additional channels to be recorded every time the the water sampler control program is activated.

14) Sampler Input Number - Binary input number which the water sampler control program will read and determine the sample number.

OUTPUT EXAMPLES

The following examples illustrate some typical outputs recorded at the Potter Marsh outlet in April 1984. During this period tides were as high as 33.1 ft; effects in the marsh were noted at tides as low as 32.1 ft. For the water sampler control program the following information was entered into the CR21:

Water stage input channel number	1
Hydrologic time interval	5 min
T1 sample interval	15 min
T2 sample interval	10 min
H1 stage	17.60 ft
H2 stage	17.58 ft
H3 stage	17.75 ft
H4 stage	18.00 ft
Sampler control port	1
Auxiliary control port	2
Differential stage rise	0.25 ft
Differential stage fall	1.00 ft
Sampler input port number	1
Auxiliary input channel numbers	2,4

For output table number 1 the CR21 was programmed to record water stage, water temperature and specific conductance every half hour (fig. 3). Output consists of the output processing table 1 (0001), the Julian day (0103-April 14), military (2300) time, and the values of the channels as measured by the CR21. Note that only the specific conductance with a range of 0 to 1,000 umho/cm was selected for output because normal flow falls within this range.

Output processing table 2 (fig. 3) is executed every 24 hours and records the average gage height for the day and the last four numbers of the Survey station number ID (3105). Note that the output table 2 does not record Julian day or time.

In this example the water sampler control program will not activate until the water stage exceeds 17.60 ft. When a 33.1 ft tide occurred on April 18 the water sampler control program executed and recorded data (fig. 4). Interpreting the data is fairly simple by remembering a few guidelines:

(1) Output table 1 will execute every half hour as programmed. Note that the specific conductance from 0600 is 1393 (greater than 1,000 umho/cm) or outside the range of this conductance probe and thus should be ignored.

(2) The '00041' indicates that the water sampler program is active but that the sampler was not activated. However, time, water stage, specific conductance (0 to 100,000 range), and water temperature are recorded.

(3) The '0051' indicates that a 5-volt pulse was sent to activate the sampler. Again, time, water stage, specific conductance,

01+0001.	02+0103.	03+2300.	04+17.48	05+1.675	06+193.5
01+0001.	02+0103.	03+2330.	04+17.48	05+1.600	06+192.0
01+0001.	02+0103.	03+2400.	04+17.47	05+1.450	06+192.0
01+0002.	02+17.46	03+3105			

Figure 3.--Example of output tables 1 and 2.

01+0001.	02+0107.	03+0530.	04+17.55	05+0.500	06+0200.
01+0041.	02+0551.	03+17.71	04+12.50	05+0.025	
01+0051.	02+0556.	03+17.78	04+096.6	05+0.000	06+1.000
01+0001.	02+0107.	03+0600.	04+17.92	05+0.000	06+1393.
01+0041.	02+0601.	03+17.94	04+106.2	05+0.000	
01+0061.	02+0606.	03+18.08	04+156.1	05+0.000	06+2.000
01+0041.	02+0611.	03+18.23	04+189.5	05+0.000	
01+0061.	02+0616.	03+18.42	04+202.1	05+0.500	06+3.000
01+0041.	02+0621.	03+18.56	04+229.0	05+0.000	
01+0061.	02+0626.	03+18.70	04+242.0	05+0.000	06+4.000
01+0001.	02+0107.	03+0630.	04+18.77	05+0.000	06+1393.
01+0041.	02+0631.	03+18.79	04+247.2	05+0.000	
01+0041.	02+0636.	03+18.89	04+260.7	05+0.000	
01+0051.	02+0641.	03+18.89	04+261.1	05+0.000	06+5.000
01+0041.	02+0646.	03+18.95	04+262.4	05+0.000	

Figure 4.--Example of output from water sampler control program.

and water temperature are recorded. The '06 + 1.000' indicates that the sampler did activate and sample number 1 was collected.

(4) The '0061' indicates that a 5-volt pulse was sent to activate the sampler because the specified differential rise (.25 ft) was exceeded since the last sample was taken. The '06 + 2.000' indicates that the sampler was activated and bottle number 2 was filled. A '06 + 0.000' indicates that the sampler was not activated.

ALASKAN CLIMATE

The instruments described have performed extremely well in the Potter Marsh study. The U.S. Geological Survey Mini-Monitor, Campbell Scientific micrologger and storage module, and the Schaevitz pressure transducer are manufactured to operate at temperatures as low as -40°F. During the period of data collection, air temperatures have reached as low as -20°F with no loss of data. Thus, preliminary indications are that the instrumentation can perform well in Alaska's harsh environment.

SUMMARY

By integrating U.S. Geological Survey and commercially available equipment, data collection at the Potter Marsh outlet was made more efficient. The system is quite flexible so additional data such as wind speed, rainfall, solar radiation, etc. can be integrated into this system. The water sampler control program can be modified by the user for different water stages or different time intervals. Output tables can be changed to add additional data such as maximum/minimum values for a specific channel or to record data at different time intervals. Finally, performance of the instruments thus far indicates they can operate in Alaska's environment.

ACKNOWLEDGEMENTS

The author wishes to thank Alex Sturrock of the U.S. Geological Survey Hydrologic Instrumentation Facility (HIF), Bay St. Louis, Mississippi, for his review of the manuscript. Thanks are also due to Jack Hardee of HIF who answered most (if not all) of our questions dealing with the setup and installation of the instruments.

FORECASTING

INFORMATION CONTENT OF RIVER FORECASTS

by Gerald J. Nibler[1]

ABSTRACT

Proper decision-making in the use of Alaska's water resources often requires knowledge of the present and future states of the hydrologic system. The National Weather Service operates a river forecast center that collects and analyzes real-time hydrometeorological data to provide public and private institutions with current and forecast conditions of Alaska's rivers.

This paper describes the types of hydrometeorological intelligence that are incorporated into the short, medium and long-range hydrologic forecasts available from the National Weather Service. Emphasis is placed on the interrelation between hydrologic factors and the types of information required for forecasts at different time spans.

INTRODUCTION

The National Weather Service's (NWS) river forecasting operation in Alaska provides flood warnings, water supply forecasts, short and extended period river forecasts for navigation, construction, wildlife management, recreation, municipal water supply interests, and reservoir inflow forecasts for resource managers and the general public who require integrated information on the climate, weather, and the rivers in order to make decisions. These decisions on river usage include those for power generation, pollution abatement, flood control, irrigation, public water supply, construction in or near the rivers, and for recreational use such as hunting, fishing and kayaking.

The primary objective of this paper is to acquaint the reader with the types of information used to produce river forecast products at the Alaskan River Forecast Center (RFC). As a unit of the NWS, the RFC has access to a wide variety of hydrometeorological information and meteorological expertise not available to the general public. It is the RFC's function to integrate this information into products useful for decision makers.

The state variables of concern in the RFC products are river stage, discharge, velocity, water temperatures, ice conditions, and how these variables change as a function of time. Forecast products for

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these variables are classified according to the time span of the forecasts and include "nowcasts" of 1 to 24 hours, short-term forecasts of 1 to 3 days, and the extended stream flow predictions of 1 to 12 weeks.

Forecasts are made for specific sites where river gage readings are available but inferences can be made for non-gaged portions of the rivers. Since this paper deals mainly with the hydrometeorological intelligence incorporated into forecasts, the reader must consider some factors that affect the type of information needed to make a forecast for a given time span. These include:

1. The drainage area and the physiography of the basin upstream of the forecast point;

2. The effects of antecedent soil moisture, snow cover conditions and the existence of glaciers upstream of the forecast point;

3. The type of causal event.

The effect of the drainage area is easily appreciated. Larger drainages have a longer response time to a causal event, i.e., the time interval between the causal event and the peak of the discharge at the forecast point. Slope, aspect, vegetation, and basin shape are also important; however, drainage area is the easiest to consider in this discussion. Small drainages with areas of about 10 to 100 square miles have response times on the order of 1 to 10 hours. Larger basins with an area of 1,000 to 2,000 square miles have response times on the order of one to two days. Major river basins with drainage areas on the order of 300,000 square miles, such as downstream points on the Yukon River, have response times that range from one to two weeks; however, the response is complicated by major tributaries located hundreds of miles apart experiencing different weather regimes on any given day. For small areas, we compute runoff from rain and snowmelt and use some technique such as unit hydrograph theory to distribute the runoff in time at the forecast point. For larger drainages, the assumptions of the unit hydrograph theory begin to break down and it is necessary to treat the smaller basins as tributaries and employ flood routing techniques to collect the forecast tributary flows and route them downstream.

Antecedent soil moisture conditions represent memory in the hydrologic system that affects runoff efficiency for several days to several weeks into the future. Snow and/or glacial ice on the basin is stored water that is potentially available for runoff depending on the surface energy conditions during the forecast period and the antecedent conditions of the snow/glacier system.

Two causal events are responsible for the bulk of stream flow variability--rainfall and snowmelt. It is important to keep in mind that rainfall is easy to observe but difficult to forecast, whereas snowmelt is difficult to observe but easier to forecast. Nowcasts and short-term forecasts can be more accurate during rainfall events, while the long-term forecasts are more accurate when snow or glacier melt is the causal event.

OBSERVATIONAL INPUT INFORMATION

The real-time rain gage network in Alaska varies significantly from basin to basin. The overall gage density is about one station per 5,000 square miles, but ranges from one station per 200 square miles on the Chena Basin to one per 10,000 square miles on the North Slope, and many large tributaries have no rain gage. Most of these stations report at least four times per day.

Surface temperature is observed at about half of the precipitation stations.

Upper air soundings are observed at 14 locations, twice per day. The upper air data are used to estimate the vertical temperature, humidity and wind profiles for computing snowmelt in mountainous terrain, freezing levels for determining the rain/snow elevation, and wind direction for orographic precipitation effects.

The NOAA polar orbiting satellites provides data on the areal extent of snow cover, snowpack surface temperature, location of likely heavy rain areas, and the extent of river ice on larger rivers such as the Yukon and Kuskokwim Rivers. Polar orbiter data are available 4 times per day at a resolution of 0.5 mile in both the visual and infra-red portions of the spectrum.

Geo-stationary satellite data provides 30-minute updates at a resolution of 1.0 mile in the visual and the infra-red. These data are particularly useful in verifying precipitation nowcasts and interpolating in data sparse areas.

Real-time river stage data are available from 56 locations. The frequency of observations varies, depending upon the telemetry used. Manual observations are taken once per day. Satellite and meteorburst telemetry can transmit on the order of once per hour.

Snow course data are used to initialize the snow accumulation and ablation model in the spring and to correct snowmelt computations during the operational season.

FORECAST INPUT INFORMATION

Forecast data include precipitation, temperature, humidity, and wind. Forecasts of these variables are derived from numerical atmospheric models run at the National Meteorological Center (NMC) in Suitland, Maryland. Figure 1 shows the output from the Limited Area

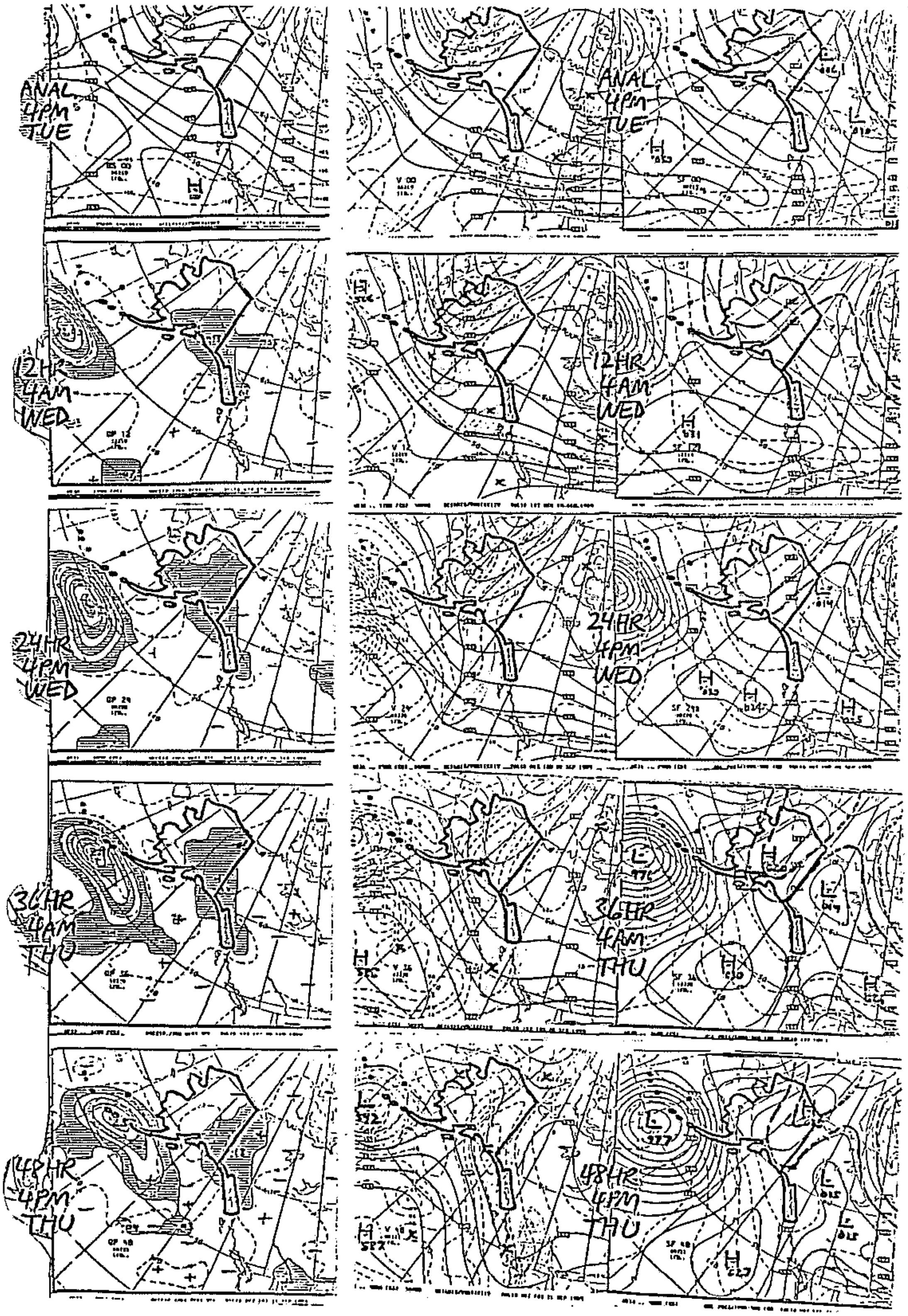

ANAL 4PM TUE
12HR 4AM WED
24HR 4PM WED
36HR 4AM THU
48HR 4PM THU

Figure 1.

Fine Mesh (LFM) model. The information contained on these maps is a bit confusing at first glance, but the important panels are the quantitative precipitation (QP), which are in the left-hand panel and the 1,000/500 mb thickness panel (SF), which is the right-hand panel. Each panel begins with the initial condition (at the top), which is an analysis of the observations. Progressing downward are forecasts or prognoses for four 12-hour periods.

The QP panel shows the isohyets of the precipitation forecast for the 12-hour period ending at the time shown on the map. In the map shown, you can see a precipitation "bullseye" moving toward the Alaska Peninsula from south of the Aleutians. When these bullseyes move over land, flood problems begin. The data on these maps are not entirely suitable for easy entry into the computer; however, digital output from the NMC models is available at the computational grid points used in the models.

Temperature is also derivable from the NMC prognosis either indirectly using the 1,000/500 mb thickness prognosis and computing an average temperature for the layer, or directly by accessing the digital data available from the NMC in a separate product. Atmospheric thickness is proportional to the mean temperature of the layer. The 1,000/500 mb layer is about from sea level to 18,000 feet.

For prognoses beyond the 48-hour limit of the LFM, we enter into the realm of uncertainty. The LFM prognoses are deterministic forecasts based on idealized solutions to the Navier-Stokes equations at a network of grid points spaced approximately 180 km apart and for 7 horizontal layers in the atmosphere. As with any predictive solution to the hydrodynamic equations, errors increase with the time. The skill exhibited by the models for forecasting quantitative precipitation beyond 48 hours is too low for practical use, however, considerable skill remains in the prediction of the long wave features in the atmosphere out to 72 hours. The center panel in Figure 1 is an example prognosis of the 500 mb height field, which is the usual representation for mid-range prognoses. Knowing the 500 mb height at a location, an estimate of the mean temperature in the lower troposhere can be made, and from the general flow pattern, a categorical estimate of precipitation is possible.

From 72 hours to 10 days into the future, we must rely on a time average of the general atmospheric circulation. Figure 2 shows an example of the 6-10 day prognosis of the 500 mb pattern and the height anomalies for the particular time of the year. Here again, we must interpret the circulation patterns to estimate the likelihood of precipitation during the valid time of the prognosis. Temperatures are estimated from the height values.

At the present time in Alaska, prognostic information for input to hydrologic models is limited to 30 days. Figure 3 shows an example of the monthly outlook for temperatures and precipitation. Here again, we are dealing with monthly averages and not discrete daily values.

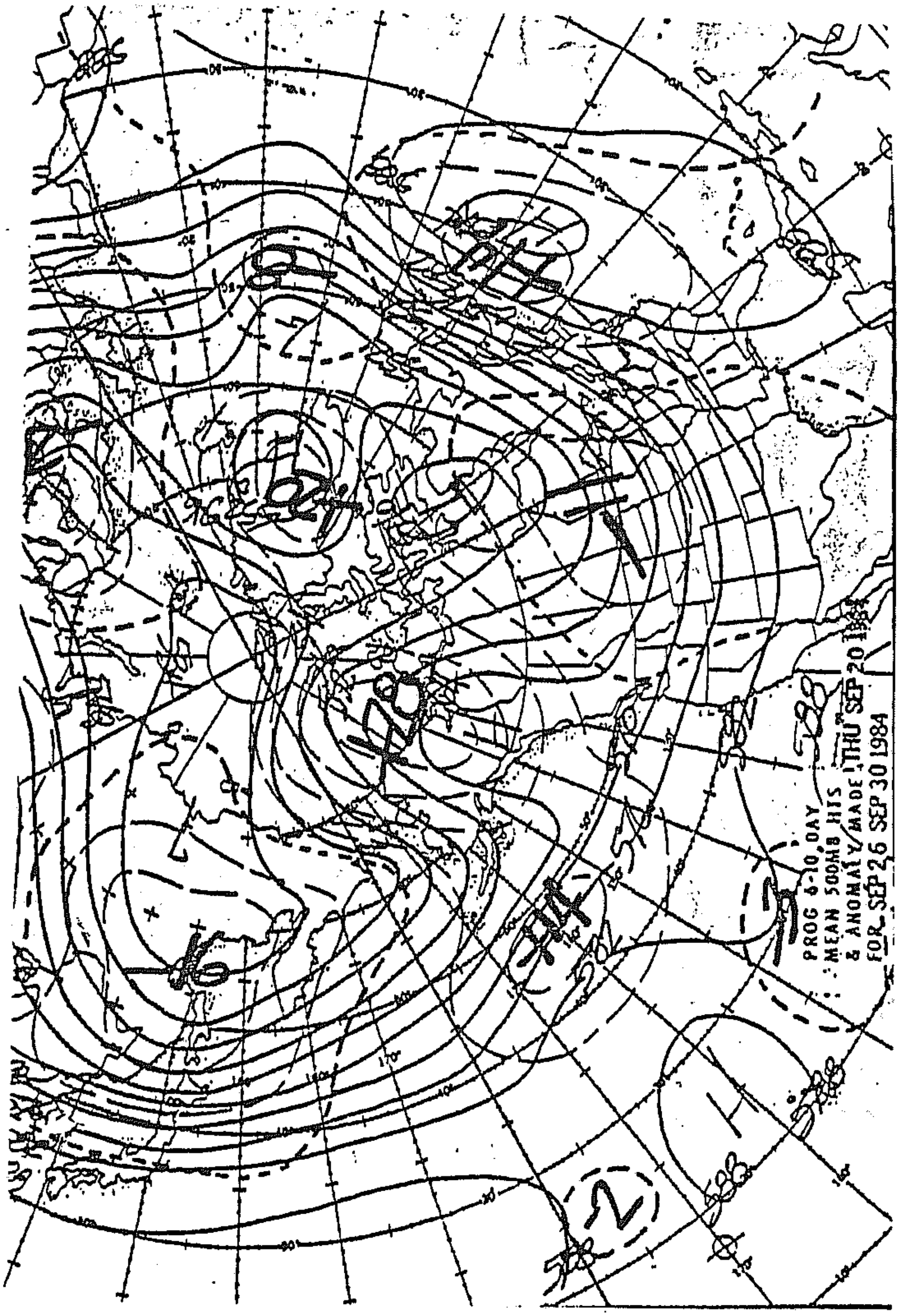
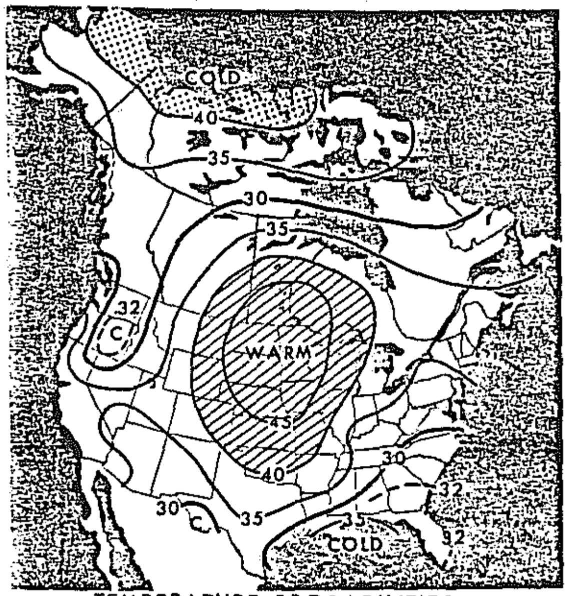

PROG 6-10 DAY
MEAN 500MB HTS
& ANOMALY MADE THU SEP 20 1984
FOR SEP 26 SEP 30 1984

Figure 2.



TEMPERATURE PROBABILITIES

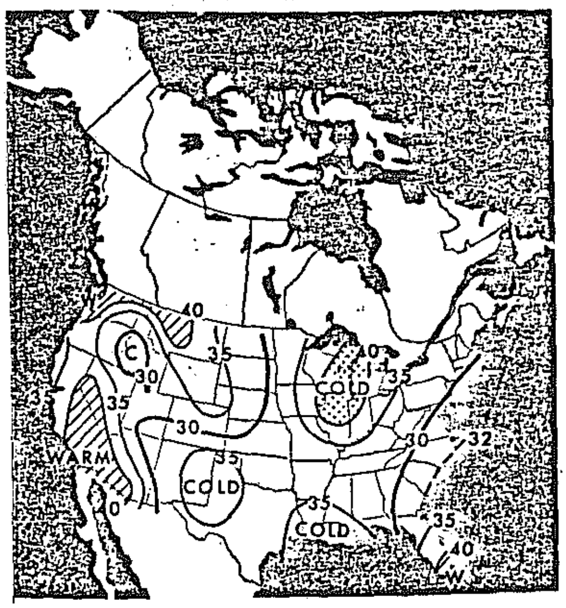
PRECIPITATION PROBABILITIES

<u>Hawaiian Outlook</u> - Temperature probabilities: WARM 30%, COLD 30%, NEAR NORMAL 40%.
Precipitation probabilities: HEAVY 30%, LIGHT 30%, NEAR NORMAL 40% <u>EXCEPT</u> HEAVY 34%, LIGHT 26%, MODERATE 40% ON WINDWARD OF SOUTHERN ISLANDS.

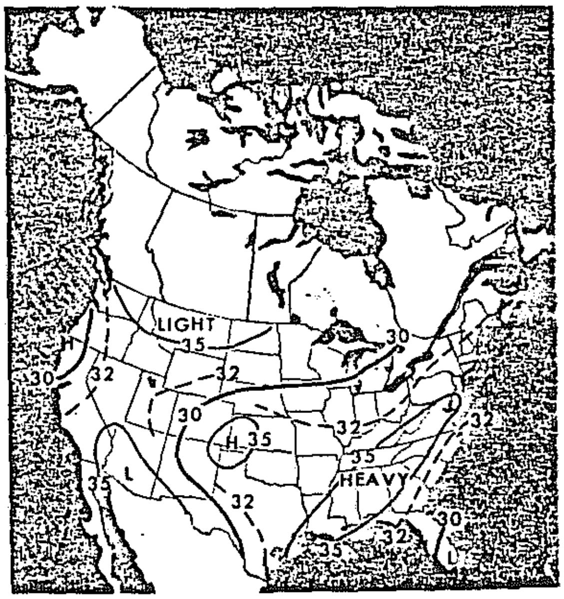
Figure 3.

90-DAY OUTLOOK FOR SEPTEMBER THROUGH NOVEMBER 1984

BASED ON PRELIMINARY REPORTS



TEMPERATURE PROBABILITIES



PRECIPITATION PROBABILITIES

The numerical ranges which apply to these two charts are given on the 7th page of the Outlook.

Figure 4.

Interpretation of the probabilities presented in this product requires some study, but basically they amount to a departure from the normals for the month and these departures can be input to a properly structured model. Seasonal outlooks are available for the "lower 48" states (Figure 4), but this product has not been extended to Alaska.

IMPLEMENTATION OF THE OBSERVED AND FORECAST INFORMATION

A description of the techniques used to ingest the various types of data into the hydrologic models used by the NWS is beyond the scope of this paper. A few general comments should help the reader appreciate the concepts involved.

The significance of the basin response time relative to forecast span rests in the potential to use observations to generate a river forecast for a given time span. Clearly, it is not possible to make a two to three day forecast based on observations for a 10 square mile drainage, but it is very feasible for a 2,000 square mile drainage. The following table shows the types of information required for forecasts of various time spans.

DRAINAGE AREA	RESPONSE TIME	FORECAST TIME SPAN 0-24 HRS.	1-3 DAYS	1-12 WEEKS
100 sq. mi.	10 hrs.	obs.	LFM	M.O.
1,000 sq. mi.	1 day	obs.	obs.-LFM	M.O.
100,000 sq. mi.	1 week	obs.	obs.	obs.-LFM-M.O.

Type of information: obs. = observations
LFM = forecasts of quantitative precipitation and temperature from the LFM model.
M.O. = Monthly Weather Outlook

When either observations or the LFM data are used to make a river forecast, the procedure is deterministic, that is, the hydrologic model is run to generate a forecast that implicitly assumes no variance due to uncertainty in the entire process. When using the Monthly Weather Outlooks for the longer time span forecasts, we see that the input information is in the form of a probability statement; thus, in principle, uncertainty in the atmospheric process is taken into account. To be realistic, the hydrologic model must also take a stochastic approach. This is accomplished in the NWS River Forecast System by employing a Monte-Carlo simulation technique to generate a probabilistic long-range hydrologic forecast using the same hydrologic models that are used in the short-range forecasts, historical climatological data and current hydrologic conditions. The climatological data used as input are biased by the departures from the normal stipulated in the Monthly Weather Outlook. Relative to regression methods, this technique provides a more comprehensive use of forecast weather conditions and a greater choice of statistics and forecast time periods. On large basins requiring the use of flood routing techniques, it is possible to make forecasts on the basis of observed river stage only. This limits the forecast time span, but with good quality data and an adequate observational network, very accurate short-term forecasts are possible since the uncertainties inherent in runoff modeling and weather forecasts are avoided.

THE FUTURE

Better space-time resolution in the observational network with the establishment of a true mesoscale system nationwide is planned during the next decade. This will be accomplished by implementing new observational systems such as digital radar, digital satellite, vertical atmospheric sounding from the satellite, vertical profilers from the surface, automation of the surface observation program, and expansion of the satellite platform network. Considerable effort is being expended in the NWS on climate modeling in an effort to produce better long-range weather outlooks. All of these systems will expand the quantity and quality of information available for use in river forecast products.

A RELATIONSHIP BETWEEN SNOW COURSE INFORMATION AND RUNOFF

by Eric A. Marchegiani [1/]

ABSTRACT

April precipitation and May snow pack data are used to predict runoff during the months of April through September for the Susitna River Basin, Southcentral, Alaska. The analysis utilizes U.S. Geological Survey (USGS) runoff data, Soil Conservation Service (SCS) snow pack data and National Oceanic and Atmospheric Administration (NOAA) precipitation data within or adjacent to the Susitna River Basin. The analysis yielded a predictive equation which has a correlation coefficient of 0.79 and predicts results within a range of approximately $\pm$ 15% of the actual runoff. The predictive equation presented here may be utilized as part of the studies supporting the development of operating regimes for the Susitna Hydroelectric Project.

INTRODUCTION

Forecasting runoff using snow course data has proven to be effective for prediction of flooding, drought events and to optimize reservoir operations for flood control, water supply and hydroelectric generation. The development of deterministic relationships between snow pack and runoff for Alaskan watersheds has been generally hampered by a lack of historical data. The data base is steadily improving, however, and now there are a number of snow courses in Alaska which have data records exceeding twenty years.

This paper develops a forecasting equation for an Alaskan basin based on an observed statistical relationship between a May 1 snow pack index and the April through September runoff. The specific intent is to present the methodology used to predict the April through September runoff within the upper and middle Susitna River basin. The validity of the forecasting equation will be discussed in relation to the data base from which it is derived.

BASIN DESCRIPTION AND METHODS

Basin Description

The Susitna River Basin (FIGURE 1, Corps 1976) contains several topographic features which result in a composite streamflow heavily influenced by specific meteorological events. The basin was shaped by

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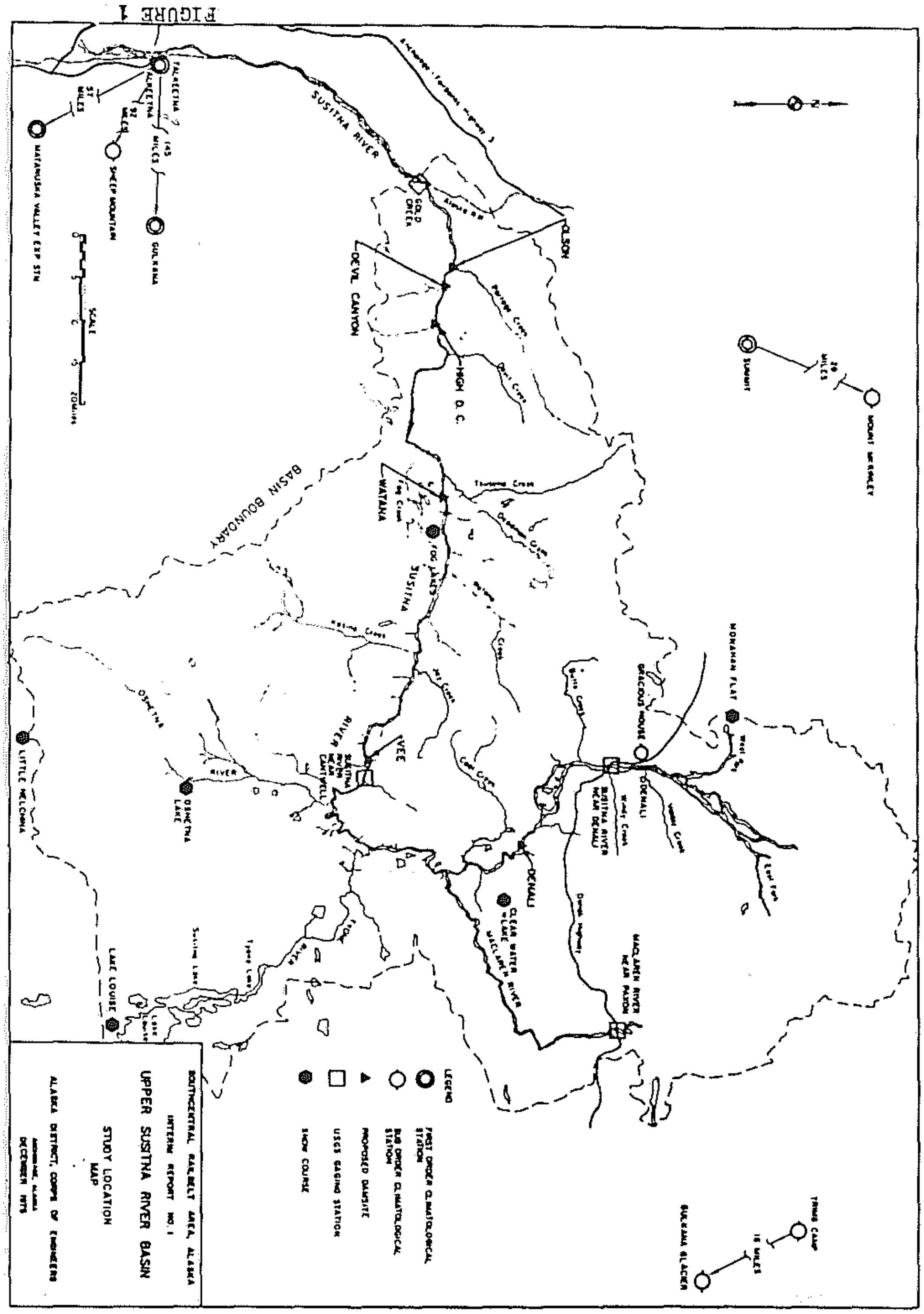
FIGURE 1


SUSITNA RIVER
TALKEETNA
GOLD CREEK
OLSON
DEVIL CANYON
HIGH D. C.
WATANA
FOG LAKES
SUSITNA
RIVER
VEE
SUSITNA RIVER NEAR CANTWELL
SUSITNA RIVER NEAR DENALI
DENALI
GRACIOUS HOUSE
MONAHAN FLAT
CLEAR WATER LAKE
MACLAREN RIVER
MACLAREN RIVER NEAR PAXSON
BASIN BOUNDARY
OSHETNA LAKE
LITTLE NELCHINA
LAKE LOUISE
MOUNT McKINLEY
20 MILES
SUMMIT
TRIMS CAMP
16 MILES
GULKANA GLACIER
145 MILES
GULKANA
92 MILES
SHEEP MOUNTAIN
57 MILES
MATANUSKA VALLEY EXP STN
SCALE
0 5 10 15 20 Miles
N
LEGEND
FIRST ORDER CLIMATOLOGICAL STATION
SUB ORDER CLIMATOLOGICAL STATION
PROPOSED DAMSITE
USGS GAGING STATION
SNOW COURSE
SOUTHCENTRAL RAILBELT AREA, ALASKA
INTERIM REPORT NO. 1
UPPER SUSITNA RIVER BASIN
STUDY LOCATION MAP
ALASKA DISTRICT, CORPS OF ENGINEERS
ANCHORAGE, ALASKA
DECEMBER 1975

various techtonic and glacial events resulting in fan shaped area comprising about 6,160 square miles and is bordered by the Alaska Range to the north, the Lake Louise plateau to the east, the Talkeetna Mountains to the southeast, and flat, low-relief areas to the southwest.

Most of the basin has a well-defined dendritic stream pattern with a main channel emanating from glacial headwaters in the Alaska Range on the north. Below the glaciers, the braided channel of the Susitna traverses a high plateau of aggraded alluvial sediments and then meanders several miles south to its confluence with the Oshetna River. The Susitna then takes a sharp turn to the west and flows through a steeply cut, degrading channel until it exits the basin below Devil Canyon and near Gold Creek. The contributing glacial area comprises only four percent of the entire basin, but summer glacial melt provides a considerable portion of the total streamflow.

The topography within the basin reflects the influence of Pleistocene glaciation. Glacial advancement over the topography gave the basin surface a rounded and smoothed appearance. The highest elevation within the basin is 13,326 feet, and the lowest elevation is 740 feet. The hypsometric curve for the area above Gold Creek (FIGURE 2) shows that the basin has reached a mature stage of development. The basin relief has a gentle slope in the upper river, develops into a steep slope in the middle river and then becomes gentle sloping in the lower river. This is somewhat reversed when compared to other mountain streams. The aggrading channel in the upper reaches of the basin has channel slopes in the range of only 4 to 7 feet per mile, while the middle basin channel drops as much as 37 feet per mile.

The flow regime of the Susitna River varies significantly with the majority of the yearly volume occurring between May and September. Summer streamflow consist mainly of snow and glacial melt combined with surface runoff from rainfall. Winter flows are restricted almost entirely to groundwater inflow.

Methods

In selecting a method to forecast the discharges during the critical time for floods, a large amount of data was reviewed to determine the data which would provide the most reliable basis for forecasting runoff. There are a number of snow courses within the basin with several years of record (SCS 1951-1984) along with a number of climate stations (NOAA 1921 - 1984) with temperature and precipitation data available. In addition, the U.S. Geological Survey has collected stream discharge data at the Susitna River at Gold Creek station (#15292000) for 33 years (USGS 1950-1983). This information was analyzed to develop a relationship between snow pack and runoff. Some of the available data in and adjacent to the Susitna Basin is illustrated in TABLE 1.

FIGURE 2

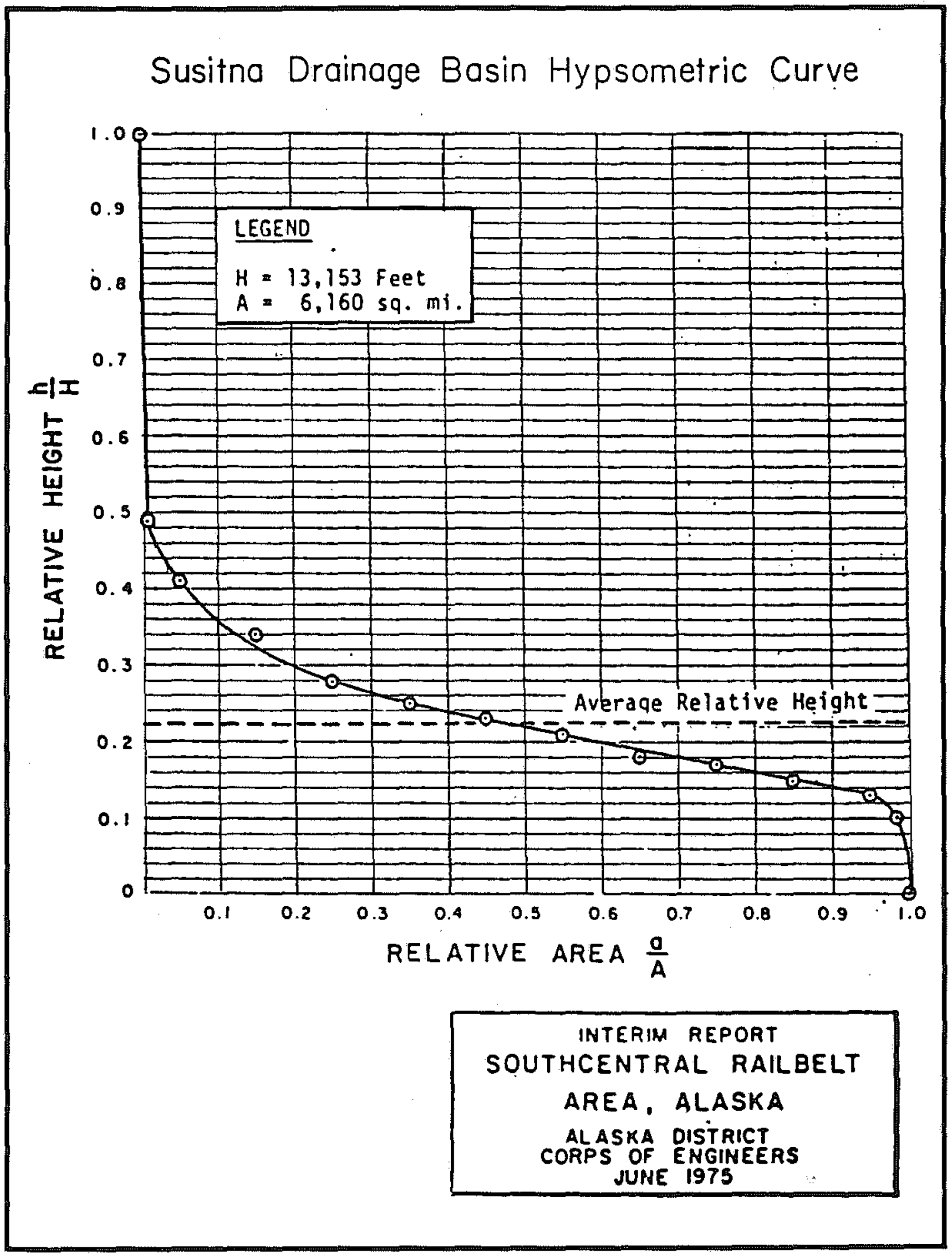

Susitna Drainage Basin Hypsometric Curve
LEGEND
H = 13,153 Feet
A = 6,160 sq. mi.
RELATIVE HEIGHT h/H
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Average Relative Height
RELATIVE AREA a/A
INTERIM REPORT
SOUTHCENTRAL RAILBELT
AREA, ALASKA
ALASKA DISTRICT
CORPS OF ENGINEERS
JUNE 1975

TABLE 1. Location and period of record of climatological stations and snow courses in or proximate to the Susitna River Basin, Alaska. Sources: NOAA (1921 - 1984), SCS (1951 - 1984).

Snow Courses

Station	Lat	Long	Elev	Begin	End	No. of Years
Horsepasture Pass 2/	62° 07'	147° 36'	4160	1968	1984	17
Clearwater Lake 3/	62° 49'	146° 58'	3100	1964	1981	18
Square Lake	62° 23'	147° 29'	2950	1964	1984	21
Monahan	63° 18'	147° 39'	2710	1964	1984	21
Lake Louise	62° 17'	146° 30'	2400	1964	1984	21
Fog Lakes No. 1	62° 47'	148° 30'	2270	1964	1984	21

Climatological Stations

Station	Lat	Long	Elev	Begin	End	No. of Years
Summit	63° 20'	149° 08'	2401	1942	1976	35
Talkeetna	62° 18'	150° 06'	345	1921	1984	64
Gulkana	62° 09'	145° 27'	1570	1942	1984	43

The Soil Conservation Service (SCS 1972) indicates that the normal practice is to correlate a May 1 Index with the April through September runoff. They also suggest other potential refinements, but due to the lack of data available it would not be practical to incorporate those refinements into the analysis. The April through September runoff is a very simple calculation made by summing the volume of water (acre-feet) at the Gold Creek station for each year.

The development of a May 1 index incorporates snow pack and precipitation (SCS 1972). The SCS collects monthly snow pack data for February through May. One might assume that the May 1 index could be the May 1 snow pack except that in a number of years the snow pack has already been depleted by early warm temperatures during spring thus adding a bias to the analysis. Therefore, the May 1 index is developed by adding the April snow pack (water content in inches) to the April precipitation (inches) for a specific station as suggested by SCS (1972).

Snow Pack Data Development

Given the above methodology one must then apply it to the available data and evaluate the results. Since there are six stations at various elevations in the Susitna basin with substantial periods of record, snow

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2/ Known also as Little Nelchina
3/ Known also as Oshetna

pack data needed to be transformed into a single weighted water content value to be used in the analysis. Data from Clearwater Lake was not utilized since it was discontinued in 1981 and would not provide for future predictions. The Horsepasture Pass station was also dropped from the analysis since the majority of its data has been estimated and not actually measured.

Therefore, only the Square Lake, Monahan, Lake Louise and Fog Lakes No. 1 stations were used to develop a weighted value of the snow pack. These snow courses were weighted thirty percent, thirty percent, twenty-five percent and fifteen percent respectively. These percentages were assigned in a graduated order rather than on an equal basis.

The data from these stations for the years 1964, 1965, 1967, and 1973 was eliminated from the analysis since two of the stations had estimated values which consisted of 55 to 60 percent of the weighted value. Further research into the actual data records indicated that in several instances the previous month's water content was also estimated. Therefore it was decided to not utilize this data in the development of a forecasting equation due to the uncertainty of the data and its potential effect on the equation.

Precipitation Data Development

There are three stations (see TABLE 1) which may be considered for the development of the May 1 index. These three stations were considered due to the length of their climatological records. The locations, period of record, and reliability of the data were reviewed for each station in order to select the best station to be used in the subsequent analysis.

The Summit station is at elevation 2401 feet which is close to the average elevation of the Susitna basin (from the hypsometric curve, FIGURE 2, 0.22 X 13,226 = 2932 feet). The station is close to the Susitna River basin and probably more representative than the other stations. It should be noted that the Summit FAA weather station was discontinued in 1976, therefore making it impossible to correlate with this station in the future.

The Talkeetna weather station is located downstream of the Gold Creek gaging station and the snow course stations. The elevation of the Talkeetna station is at 345 feet which is substantially less than the mean elevation of the basin (2932 ft.) and also substantially less than the other two stations. The station has a long continuous record and will probably continue to operate in the future.

The Gulkana station is located outside of the Susitna River basin but is adjacent to the basin and is characteristic of an interior weather station. Although the Gulkana station elevation (1570 ft.) is not as close to the mean elevation (2932 ft.) as the Summit station it is substantially closer than the Talkeetna station. It should be noted that the April precipitation for the Gulkana station is small in relative comparison with the snow pack water content, thus only adding a small increment to the May 1 index. This station has a long continuous record which will probably be continued. Therefore, data from this station could be incorporated in the future to refine our analysis if necessary.

As a part of the Susitna Hydroelectric Project studies a number of other stations have been established within the Susitna River basin during the past three years. These stations have a relatively short period of record in comparison to the previously mentioned stations but they are in closer proximity to the dam sites. They will probably aid in the refinement and development of future runoff predictions.

Confidence Limit Development

In order to better test whether data should be eliminated or not, it was decided to establish confidence intervals around the regression line. The following equations were utilized from Spiegal (1975) and Yevjevich (1978) to establish the upper and lower limits on the predictive equation.

$$Y_{1,2} = Y_o \pm t_p S_{ey} \sqrt{1 + \frac{1}{n} + \frac{(X_i - \bar{x})^2}{n S_x{}^2}}$$

where: $Y_{1,2}$ = upper and lower limits

$t_p = t_{1 - \frac{a}{2}, d}$ = students t distribution for a given probability (a) and degrees of freedom (d=n-2)

X_i = the May 1 Index for which an upper and lower limit is desired.

$\bar{x}$ = the mean of the observed May 1 Index values

Y_o = $a X_i^b$ where a & b are coefficient of the regression line.

S_x^2 = standard deviation of May 1 Index.

n = number of data points.

S_{ey} = standard deviation of residuals

$$S_{ey} = S_y \sqrt{\frac{(n-1)(1-r^2)}{n-2}}$$

where S_y = square root of the standard deviation of the runoff

r^2 = correlation coefficient

RESULTS

TABLE 2 illustrates the water content for each of the stations along with the weighted value as calculated for each of the years.

TABLE 2. April 1 water content weighted value (inches).

No.	Year	(30%) Square Lake	(30%) Monahan	(25%) Lake Louise	(15%) Fog Lake No. 1	Weighted Value
1	1964	3.6e	4.1e	3.2	1.9	3.40
2	1965	3.6e	5.5e	3.1	2.2	3.84
3	1966	2.9	6.1e	3.9	4.6	4.37
4	1967	4.6e	5.2	6.0e	4.8	5.16
5	1968	3.3	8.2	4.6	8.4	5.86
6	1969	2.6	3.2e	2.7	2.2	2.75
7	1970	1.9	4.0e	2.1	2.8	2.72
8	1971	3.7	10.1e	3.6	8.4	6.30
9	1972	5.8	9.0	6.8	7.5	7.27
10	1973	4.6e	7.5e	4.2	8.0	5.88
11	1974	3.8	4.2e	4.7	4.8	4.30
12	1975	5.1	10.0	4.9	6.6	6.75
13	1976	2.8	5.9	2.9	4.1	3.95
14	1977	4.3	9.6	4.5	7.4	6.41
15	1978	3.1	7.0	4.0	3.5	4.56
16	1979	4.5e	9.1	4.5	7.4	6.32
17	1980	4.2	6.9	4.7	7.4	5.62
18	1981	3.9	7.2	2.7	3.7	4.56
19	1982	6.7	5.0	3.6	5.6	5.25
20	1983	5.1	7.0	4.2	4.6	5.37
21	1984	2.8	8.6	3.4	5.5	5.10

The above weighted water content was then added to the April precipitation for each of the three stations previously identified in order to develop a May 1 index. TABLE 3 illustrates the April precipitation and the May 1 index for each station.

e = Estimated value

TABLE 3. April precipitation and May 1 index for the Talkeetna, Gulkana, and Summit weather service stations.

	Gulkana		Summit		Talkeetna	
Water Year	April Precip. (inches)	May 1 Index (inches)	April Precip. (inches)	May 1 Index (inches)	April Precip. (inches)	May Index
1966	0.11	4.48	0.46	4.83	1.94	6.31
1968	0.26	6.12	0.72	6.58	1.50	7.36
1969	T 4/	2.75	0.22	2.97	0.29	3.04
1970	0.26	2.98	2.14	4.86	2.33	5.05
1971	0.09	6.39	0.33	6.63	0.81	7.11
1972	0.27	7.54	0.23	7.50	1.40	8.67
1974	T	4.30	0.89	5.19	1.63	5.93
1975	0.37	7.12	0.88	7.63	2.18	8.93
1976	0.28	4.23	0.14 5/	4.09	0.37	4.32
1977	0.45	6.86			4.51	10.92
1978	0.01	4.57			0.33	4.89
1979	0.21	6.53			2.96	9.28
1980	T	5.62			0.52	6.14
1981	T	4.56			0.12	4.68
1982	0.19	5.44			0.39	5.64
1983	0.67	6.04			2.58	7.95
1984						

The May 1 index for each of the stations was regressed against the actual total runoff (acre-ft) for the period of April through September for the USGS Susitna River at Gold Creek gaging station. This yielded the following equations and regression coefficients.

Gulkana

$$\text{Runoff} = 2{,}611{,}481.62 \text{ (May 1 Index)}^{0.49}$$
$$r^2 = 0.61$$

Summit

$$\text{Runoff} = 1{,}892{,}131.24 \text{ (May 1 Index)}^{0.64}$$
$$r^2 = 0.88$$

Talkeetna

$$\text{Runoff} = 2{,}871{,}571.76 \text{ (May 1 Index)}^{0.38}$$
$$r^2 = 0.47$$

TABLE 4 illustrates the actual runoff, and the predicted runoff and percent error for each station.

4/ T = Trace of precipitation, assumed equal to zero

5/ Summit FAA weather station discontinued operation in 1976.

TABLE 4. Actual April to September runoff ($X10^6$ acre-ft), predicted runoff, and percent error for the Gulkana, Summit and Talkeetna weather stations.

	Actual	Gulkana		Summit		Talkeetna	
Water Year	April-September Runoff	Predicted Runoff	Percent Error	Predicted Runoff	Percent Error	Predicted Runoff	Percent Error
1966	5.92	5.44	-8	5.45	-8	5.82	-2
1968	6.19	6.33	+2	6.48	+5	6.12	-1
1964	3.53	4.28	+21	4.15	+17	4.40	+25
1970	5.04	4.45	-12	5.47	+8	5.34	+6
1971	6.55	6.47	-1	6.51	-1	6.09	-7
1972	6.82	7.01	+3	6.97	+2	6.57	-4
1974	5.00	5.33	+7	5.67	+13	5.68	+14
1975	6.75	6.82	+1	7.04	+4	6.64	-2
1976	5.10	5.29	+4	4.96	-3	5.03	-1
1977	6.48	6.70	+3			7.18	+11
1978	4.78	5.49	+15			5.27	+10
1979	6.08	6.54	+8			6.74	+11
1980	6.66	6.07	-9			5.75	-14
1981	7.52	5.48	-27			5.19	-31
1982	5.96	5.98	0			5.57	-7
1983	6.10	6.29	+3			6.35	+4

After reviewing correlation coefficients, percent error (TABLE 4), period of record, and location of the stations, the Gulkana Station was selected for utilization in developing a predictive equation. The Summit Station was eliminated from further analysis since its record terminated in 1976. The Talkeetna Station data yielded a lower correlation coefficient and higher percent error than the data from Gulkana. Therefore the Gulkana Station was used to develop the predictive equation.

The purpose of identifying a relationship between the May 1 index and runoff is to be able to predict summer runoff. There are a number of years in which precipitation during the period of June through September is so large that it masks the relationship between snow pack and runoff. The precipitation for the months of June through September during 1981 was high in comparison to the other years studied. Therefore in an effort to improve the relationship between snow pack and runoff, the 1981 data was removed from the analysis (See TABLE 5). This resulted in the following equation:

$$\text{Runoff}_2 = 2{,}428{,}171.42 \ (\text{May 1 Index})^{0.52}$$
$$r^2 = 0.79$$

TABLE 5. Gulkana weather station data used to develop snow pack vs. runoff equation.

Water Year	April 1 Weighted Value (inches)	April Precipitation (inches)	May 1 Index (inches)	April-September Runoff (acre-ft) $X10^6$	Predicted Runoff (acre-ft) $X10^6$	Percent Error
1966	4.37	0.11	4.48	5.92	5.30	-11
1968	5.86	0.26	6.12	6.19	6.23	+1
1969	2.75	T	2.75	3.53	4.11	+16
1970	2.72	0.26	2.98	5.04	4.29	-15
1971	6.30	0.09	6.39	6.55	6.37	-3
1972	7.27	0.27	7.54	6.82	6.95	+2
1974	4.30	T	4.30	5.00	5.19	+4
1975	6.75	0.37	7.12	6.75	6.74	0
1976	3.95	0.28	4.23	5.10	5.14	+1
1977	6.41	0.45	6.86	6.48	6.61	+2
1978	4.56	0.01	4.57	4.78	5.35	+12
1979	6.32	0.21	6.53	6.08	6.45	+6
1980	5.62	T	5.62	6.66	5.96	-11
1982	5.25	0.19	5.44	5.96	5.86	-2
1983	5.37	0.67	6.04	6.10	6.19	+2
1984	5.10	0.04	5.14	-	5.69	-

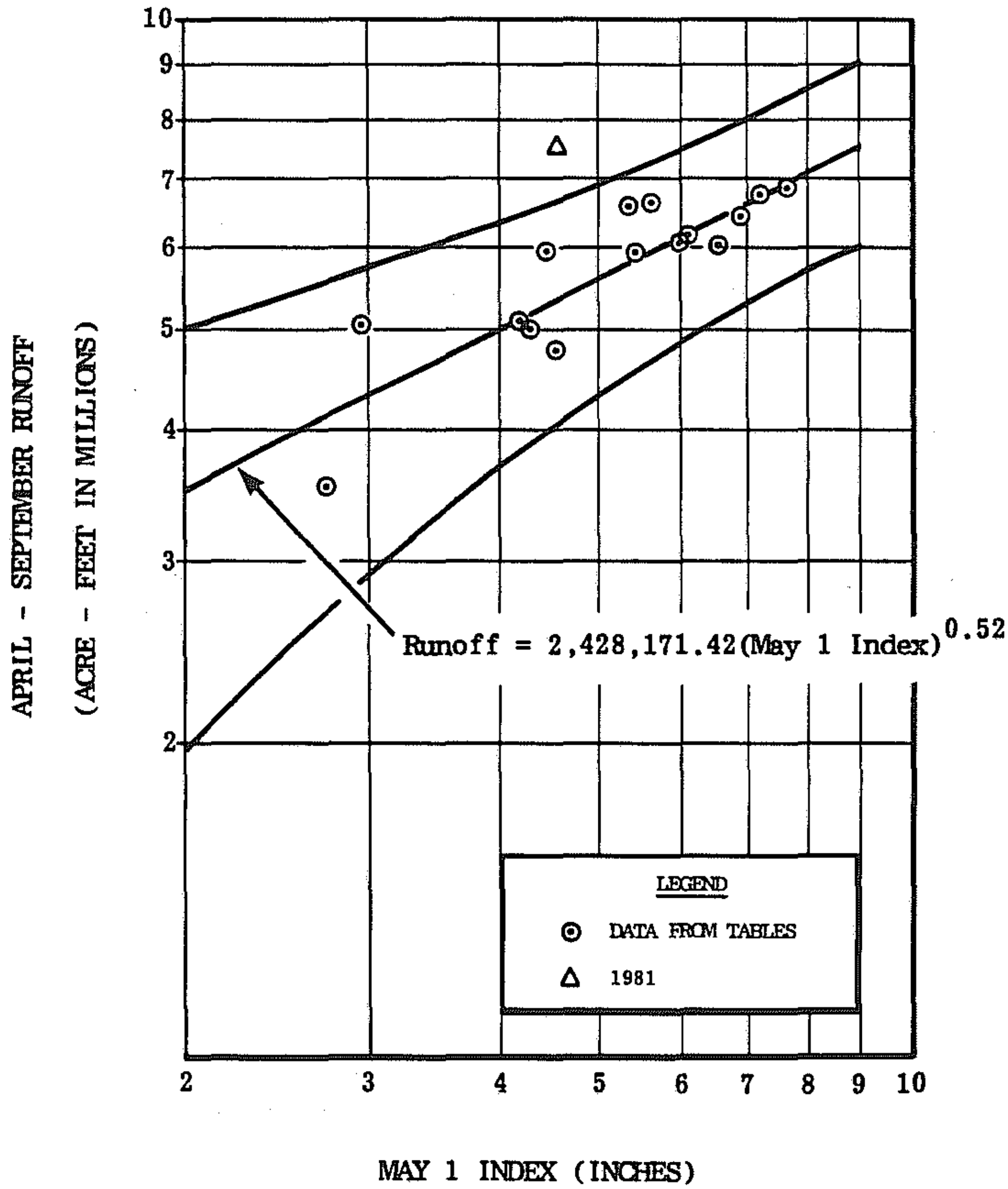
In order to test whether the 1981 data should be removed, confidence intervals were established about the predictive equation as shown on FIGURE 3. The confidence interval was established at the 95% level with two degrees of freedom. The data for 1981 falls outside of the confidence interval therefore removal of this data point is indicated. A second check on the Talkeetna data was made to see if removal of the 1981 data would improve its correlation coefficient and percent error. The removal yielded the following regression equation correlation coefficient and range of predicted error.

$$\text{Runoff} = 2{,}431{,}142.94\ (\text{May 1 Index})^{0.46}$$
$$r^2 = 0.74$$
$$\text{Range} = \pm\ 15\%$$

As one can observe from TABLE 4, the removal of the 1981 data has improved the percent error and the correlation coefficient has increased from 0.47 to 0.74. This seems to indicate that the Talkeetna station and the Gulkana station both could contribute toward the development of a predictive equation. Since the Gulkana station has a higher correlation coefficient (0.79 vs. 0.74) it is utilized. Therefore, only the following predictive equation derived from the Gulkana data should be used.

$$\text{Runoff} = 2{,}428{,}171.42\ (\text{May 1 Index})^{0.52}$$

FIGURE 3 - Runoff V.S. May 1 Index
Susitna River Basin at Gold Creek
September 1984



DISCUSSION

There are a number of observations that one can draw from the above results. The predictive equation developed has a correlation coefficient 0.79. In addition, the percent error for predicting actual values ranged from +16% to a -15% (See TABLE 5) although most of the error was substantially less than those extremes. This would seem to indicate that predictions of runoff for the period of April through September on May 1 may be in error by approximately $\pm$15%. This prediction would only be valid as long as there is not substantial precipitation in the later part of the period. A precipitation event of this type could not be predicted several months in advance, therefore the equation developed above is probably the best approximation of the runoff. TABLE 5 and FIGURE 3 both illustrate, as one would expect, that both extremes (wet and dry periods) are not predicted very well but the average conditions will be approximated by the predictive equation.

This paper presents a methodology and a relationship between the May 1 index (snow pack and precipitation) and runoff for the upper Susitna River drainage. Minor modifications needed to be made in both the snow pack data and the precipitation data in order to arrive at a predictive equation which would predict runoff within the basin with a reasonable degree of certainty. The relationship developed for the Gold Creek gaging station should give representative results for good snow pack and precipitation data. This equation could be used to predict the runoff volume which is needed for the development of a reservoir regulation model.

While the Talkeetna station was not selected to develop the predictive equation, future analysis should also consider its utility. Further modification of the equation and methodology should occur given the data base which is presently being expanded.

ACKNOWLEDGEMENTS

The Author wishes to express his gratitude to the Alaska Power Authority, which made it possible to develop this paper. The review by George Clagget, Snow Survey Supervisor helped the author in finalization of the paper. A special thanks is extended to Cleve Steward of E.W. Trihey (EWT) and Associates for his review of the technical aspects and his constructive comments.

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IMPACT OF GLACIERS ON LONG-TERM BASIN WATER YIELD

Stephen R. Bredthauer [(1)] and William D. Harrison [(2)]

ABSTRACT

Several glacierized basins in Alaska, including the Bradley Lake basin, are being developed for major water resource projects. Although long-term discharge records exist, these records may yield an inaccurate measure of current basin water yield, due to significant changes in water supply from the glacierized portions of the basins.

Case histories from other parts of the world and mass balance studies from several Alaskan glaciers are presented to illustrate the changes in water supply from glacierized basins. Annual changes in basin water yield for the Bradley Lake basin are then analyzed, using the Tangborn runoff-precipitation model. All estimated impacts of annual glacier mass balance changes on annual water yield are removed. A second flow scenario is also presented, in which the long term trend of glacier mass wasting is removed from the flow records. The impacts of the adjusted flows on power planning studies are then discussed.

INTRODUCTION

Bradley Lake is located on the Kenai Peninsula of Alaska near the upper end of Kachemak Bay (Figure 1). The basin is being developed for hydroelectric power by the Alaska Power Authority. The drainage area covers 56.1 square miles, of which approximately 38 percent is glacierized.

Streamflow data have been collected by the U.S. Geological Survey (USGS) at the Bradley Lake outlet since October 1957. However, variations from the recorded data are known to have occurred. Runoff from Nuka Glacier switched basins from Nuka River to Bradley River in late 1970 or early 1971, and back again in 1983. In addition, annual yield of the Bradley Lake basin is modified by the storage of precipitation in the glaciers. The logic used in adjusting existing flow records for the effect of glaciers is presented in this paper.

GLACIERS AND WATER SUPPLY

Glacierized basins possess water reservoirs in solid form, regulating runoff in unique ways. On the short time scale, there is beneficial regulation during dry weather that would normally produce low flows in

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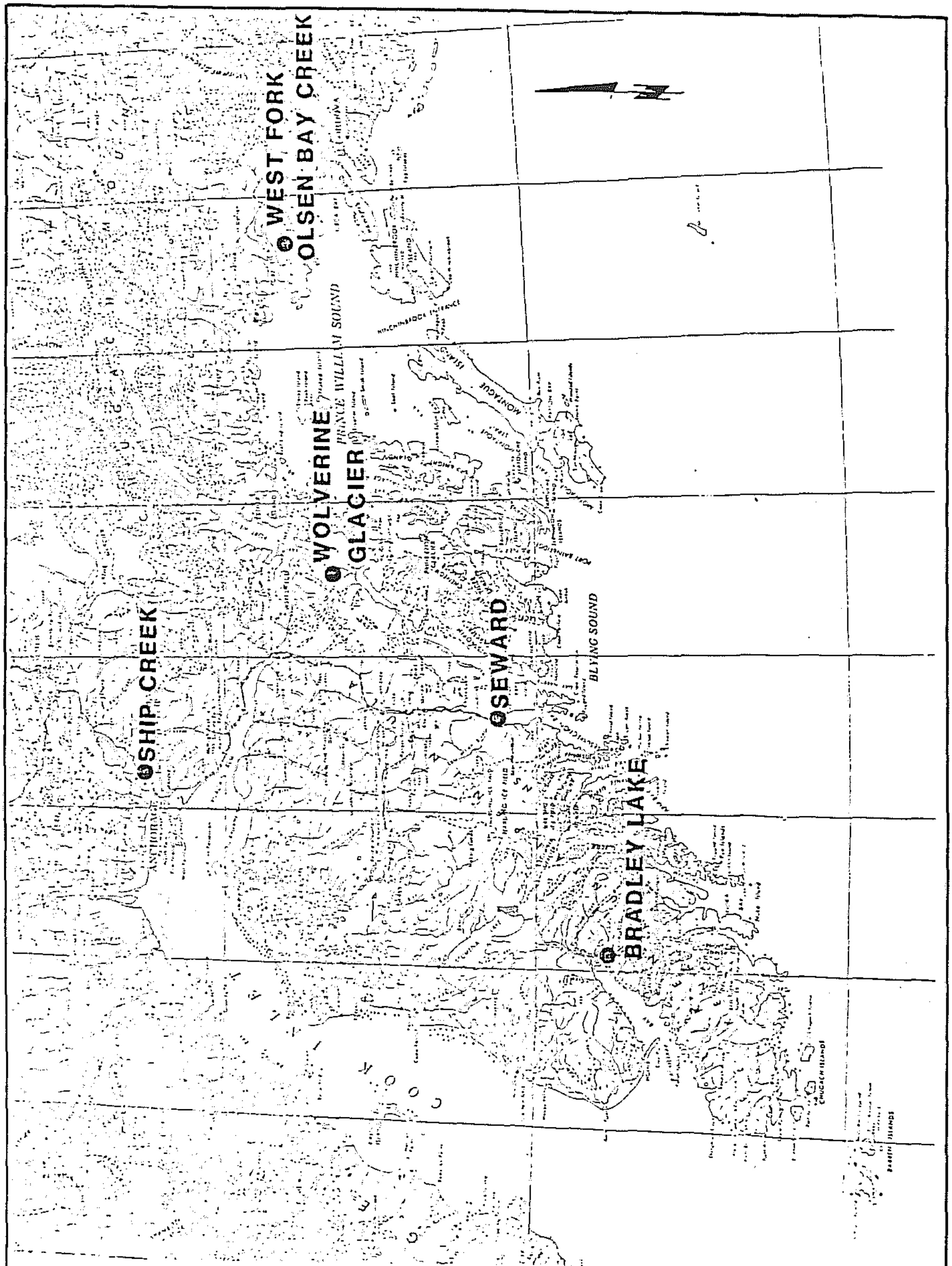

Stone and Webster Engineering Corporation, 1983.

FIGURE 1 - Location Map

an unglacierized basin, as even lightly glacierized basins usually generate copious glacier melt water (Krimmel and Tangborn, 1974). On the long-time scale, depletion of the ice reservoir makes prediction of future water supplies difficult by conventional techniques.

Before discussing climate, which is the ultimate control on glacier behavior, glacier response to climate changes must be described. Consider a sudden and permanent climate change less favorable for a glacier. The glacier will respond by shrinking its ablation area (that lower portion of the glacier where melting exceeds snow accumulation) until its net annual balance of ice mass lost is zero. The glacier is now in equilibrium with the new climate. The length of time to attain equilibrium depends upon the details of the flow of ice from the upper, "accumulation" area of the glacier down to the ablation area. These details are only partially understood. Theory suggests that typical response times may be on the order of a century for glaciers such as those in the Bradley Lake basin. Water may therefore be produced from storage for many decades after permanent climate change.

However, climate trends of the last century indicate that this simple scenario is improbable. Since 1900, the annual temperature of the Northern Hemisphere has not been constant, but instead steadily increased until 1940. If such a trend continued, the increased temperature would tend to remove water from ice storage until glaciers disappeared, although at a steadily decreasing rate. However, the Northern Hemisphere cooled from the 1940's until the mid-1960's, when temperatures became relatively stable. Today's cooler temperatures suggest that significantly less water is now being produced from storage than in the early 1950's, regardless of glacier response time.

Local temperature trends can be rather different and more complex than global trends. Also, temperature itself is not a unique indicator of glacier behavior, as precipitation and other factors are equally important. For perspective on the Bradley Lake basin, case histories have been examined from areas where more data are available .

Aletsch Glacier is the largest in Switzerland, with an area of 65 km^2. As seen in Table 1, prior to 1952 Aletsch Glacier was supplying about 17% of the basin runoff from ice loss, but after 1952 the average was negative. The loss of runoff from ice melting was partially compensated for by a 6% increase in precipitation, but the runoff still decreased by 12% (Anonymous, 1983).

TABLE 1. ALETSCH GLACIER WATER BALANCES

Basin Averages	1920-1952	1952-1977
Precipitation	2.22 m/yr	2.36 m/yr
Water from Ice Storage	0.40	-0.05
Runoff	2.42	2.08

The decreased runoff from Aletsch Glacier appears typical of conditions in the Swiss Alps. The 50% glacierized Grande Dixence hydroelectric project, the largest in Switzerland, suffered an unexpected 13% shortfall of water during its first 14 years of operation up to 1979, due to the loss of water production from ice storage (Bezinge, 1979). However, the mapping of terminal positions of Swiss glaciers indicates that, on the average, the glaciers are presently stable (Anonymous, 1983).

Norway has a large glaciological program in connection with hydropower development. Using a balance model derived from climatic data, estimates have been made of the long-term water production from glacier storage in the 24% glacierized basin Oyreselv in western Norway (Haakensen and others, 1982). These glaciers have produced only about 2% of the runoff from 1922 through 1972, and their smoothing effect on annual runoff has been only moderate. The moderate influence of glaciers at this site may be typical of maritime climates (as opposed to drier environments) due to the larger flow of water through the hydrologic system. For hydropower planning studies, the Norwegians use the glacier corrected annual runoff.

A large mass loss from East Fork Glacier (in the Susitna River basin, Alaska), crudely estimated to be an average of 50 meters total loss between 1949 and 1980, indicates that significant water production from glacier ice storage occurred (R&M and Harrison, 1981). However, the mass loss of Gulkana Glacier, 80 km to the east, has been relatively small since measurements began in 1966. This suggests that water production was considerably larger during the earlier part of the 1949-1980 interval. In fact, the balance of Gulkana Glacier seems to have been stable for the past few years, although the data are not yet completely reduced or published (Larry Mayo, private communication).

Balance measurements on Wolverine Glacier on the Kenai Peninsula, Alaska, began in 1966 (Meier and others, 1980). These data show a strongly positive balance since 1976 (Mayo and Trabant, 1982). An important feature of this 72% glacierized basin is that although precipitation has been lost into ice storage since 1976, the basin runoff has <u>increased</u> because of the dominance of the increased precipitation. Although precipitation also increased after 1952 on Aletsch Glacier in Switzerland, it was not sufficient to compensate for the cessation of water production from ice storage. This example illustrates that when analyzing runoff, not only changes in ice storage but also changes in precipitation must be considered.

An average water equivalent thickness change of the Bradley Lake glaciers between 1952 and 1979 has been estimated from sequential aerial photos. The loss amounts to 14 feet of water equivalent averaged over the glaciers, although variations in the estimate could cause the change to range from a gain of 4 feet to a loss of 32 feet. Although the termini of Kachemak and Nuka Glaciers have retreated, the upper glaciers have actually thickened. This suggests that the balances toward the end of the 1952-1979 interval have been positive, despite the cumulative negative balance. This seems consistent with data from Wolverine Glacier and from Gulkana Glacier which suggest little recent water from ice storage. It is possible that the switch to comparatively stable glacier balances that were typical of the late 1940's or early 1950's in much of the Northern Hemisphere may have occurred slightly later in Central and Southern Alaska. When correcting the Bradley Lake flow records for the effects of glaciers, it is expected that the effects will be stronger in the earlier part of the records. This is a safe assumption that can be used as a check on the more detailed Tangborn balance model described below.

TANGBORN RUNOFF-PRECIPITATION MODEL

Tangborn (1980) has proposed a runoff-precipitation (RP) model for estimating long-term glacier balances by relating measured climatic variables with differences in runoff between a glacierized basin and nearby nonglacierized basin. The model, described in Tangborn (1980) and SWEC (1983), assumes that the difference in annual runoff between nearby glacierized and nonglacierized basins is caused by ice storage or release from the glaciers. The annual water balance (precipitation minus the sum of runoff and net evaporation-condensation) of the nonglacierized basin is assumed to be approximately zero. The annual precipitation at each basin is estimated using the annual precipitation at a low-elevation index station multiplied by coefficients representative of each basins. Coefficients can be determined if the glacier mass balance, runoff from each basin, and precipitation at the index station are all known for a period greater than one year. The annual balance of the glacierized basin is then determined by dividing the annual change in storage by the glacierized fraction of the basin area.

Before applying the model to the Bradley Lake basin, the model was tested against the measured annual mass balances at Wolverine Glacier, located 25 mi (40 km) northeast of Seward and 75 miles (120 km) northeast of the Bradley Lake basin. The Wolverine Creek basin is heavily glacierized, with 72% of the 9.5 sq. mi. (24.9 sq. km.) basin covered by Wolverine Glacier. Annual mass balance data on Wolverine Glacier exist since Water Year (WY) 1966 (Mayo and Trabant, 1982). The basin streamflow was gaged from WY 1967 through 1978. Two nonglacierized basins (Ship Creek and West Fork Olson Bay Creek) were used to calibrate the model. Seward was selected as the most applicable weather station, as it is a coastal station, measuring the major weather patterns from the Gulf of Alaska. The locations of the drainage basins and the weather station are shown on Figure 1.

Results for the 1967-1978 period are shown in Table 2. The Tangborn model appears to give reasonable results, with estimated mass balances generally consistent with water being stored or released by the glaciers. Year-to-year variations in magnitude may be caused by spatial variations in the annual precipitation patterns.

TABLE 2 - TANGBORN
RUNOFF-PRECIPITATION MODEL
VERIFICATION TEST RESULTS

Year	Measured Balance (In. of Water)	Estimated Balance (B_a) from Nonglacierized Basins: Ship Creek (In. of Water)	W. Fork Olsen Bay Creek (In. of Water)
1967	-61.4	-41.9	-70.3
1968	-11.6	-29.5	-13.9
1969	-2.6	-26.2	-8.3
1970	76.8	100.0	106.2
1971	25.6	57.6	50.5
1972	-28.9	-28.5	-23.9
1973	28.9	21.5	25.0
1974	-40.7	-85.3	-99.2
1975	8.5	52.7	57.4
1976	-20.5	-17.6	-29.8
1977	80.9	113.1	126.9
1978	40.0	-20.9	-25.4
Total 1967-1978	95.0	95.0	95.2

(Stone & Webster Engineering Corporation, 1983.)

APPLICATION TO BRADLEY LAKE BASIN

After the above check the Tangborn runoff-precipitation model was applied to the glaciers of the Bradley Lake basin. No annual mass balance data exist for glaciers in the Bradley Lake basin. To circumvent this problem, existing aerial photographs from 1952 and 1979 were used to photogrammetrically determine the change in mass of the glaciers. Although not all of the glacierized areas were covered by the photography, there are sufficient data to obtain an estimate of mass change. These were used to help determine the different responses of the glaciers to climate changes. The average water equivalent loss for the Bradley Lake glaciers between 1952 and 1979 was estimated as 14 feet over the glacierized area.

Flow estimates from Bradley River in Water Years 1953-1957 were required for the flow records to match the balance estimates from the photogrammetric analysis, in order to distribute the annual mass storage or loss of the glaciers. The only other glacial river on the Kenai Peninsula with records back to WY 1953 is the Kenai River at Cooper Landing. Consequently, a linear regression equation relating annual runoff at Bradley River to that at Kenai River was established to extend Bradley River flows to WY 1953. Prior to determining the linear regression equation, Bradley River streamflow records were modified for the switching of drainage basins of runoff from Nuka Glacier (Alaska Power Authority, 1984).

Ship Creek annual runoff data were used for the nonglacial flow data. Seward was selected as the nearest weather station for data representative of that at Bradley Lake. It was assumed that 38% of the Bradley Lake basin was glacierized.

The Tangborn RP model was applied to Water Years 1953-1979 to estimate annual mass balance of the Bradley Lake glaciers. The results of the analysis are shown in Figures 2 and 3. Of the 168 inches of water equivalent contributed by the glaciers, 44 inches were distributed to Water Years 1953-1957, prior to stream gaging at Bradley Lake. Consequently, the adjustment to streamflow during the period of WY 1958 - WY 1979 was (0.38) (-124) = -47 inches total runoff, or an average annual decrease of 9 cfs. As can be seen from Figure 2, there are considerable year-to-year variations in mass balance changes. Note that in years when the glacier mass balance is positive, streamflow records indicate flows lower than those which would have occurred if the glacier had not gained mass. Consequently, streamflow values were increased in those years.

The adjusted flows in Figure 3 are the estimated flows if the glacier did not change in mass in any year (i.e., no water was stored or released from ice storage in the glaciers). As a planning tool, this scenario does not allow the major benefit of having a hydroelectric project on a glacial river, that of having a sustained water supply under normal drought conditions. If climate conditions during the first 25 years of the project life were similar to those of the existing period of record, then flows adjusted for the basin switching by Nuka Glacier runoff would be representative. However, it has already been shown that an estimated 14 feet of water equivalent has been contributed by melting away of the glaciers. A minor shift in climate could have caused the glaciers to be back at the same state as they were at the beginning of the period. Consequently, a second flow scenario was developed in which the trend of glacier wasting was removed from flow records. In this scenario, glaciers have the same mass at the beginning and end of the period of record. The adjusted flow records reflect the year-to-year storage or wasting caused by differences in climatic conditions, thus providing the increased water supply during drought conditions. The removal of the glacier wasting trend decreases the average annual runoff by about 9 cfs from that estimated after adjusting the basin switching by Nuka Glacier runoff. Decreases in annual runoff ranged from 7 cfs to 18 cfs.

Although this second flow scenario has virtually the same average annual runoff as the first scenario (in which all glacier mass changes were removed), the first flow scenario has a period of annual runoff (WY 1968 through 1969) which is lower than any other. Since the more severe annual runoff sequence provides a more conservative approach to estimating reliable hydroelectric energy, the flow scenario in which all glacier mass changes were removed was selected for power planning studies.

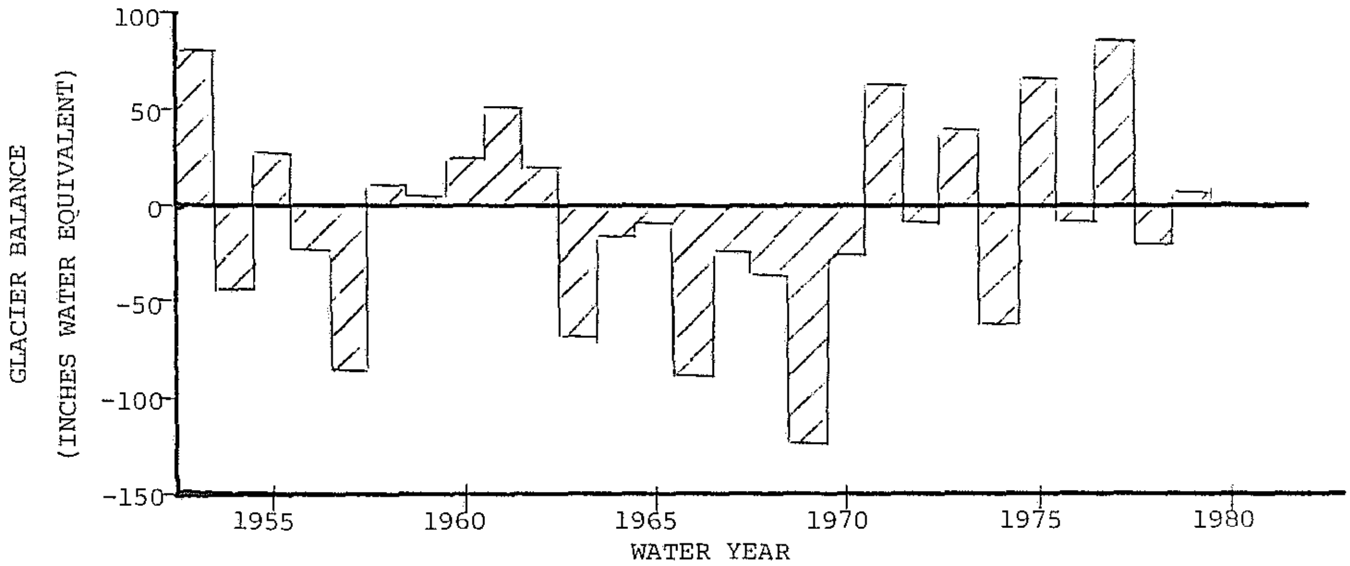

FIGURE 2 - Estimated Annual Glacier Mass Balance Changes, Bradley Lake Basin

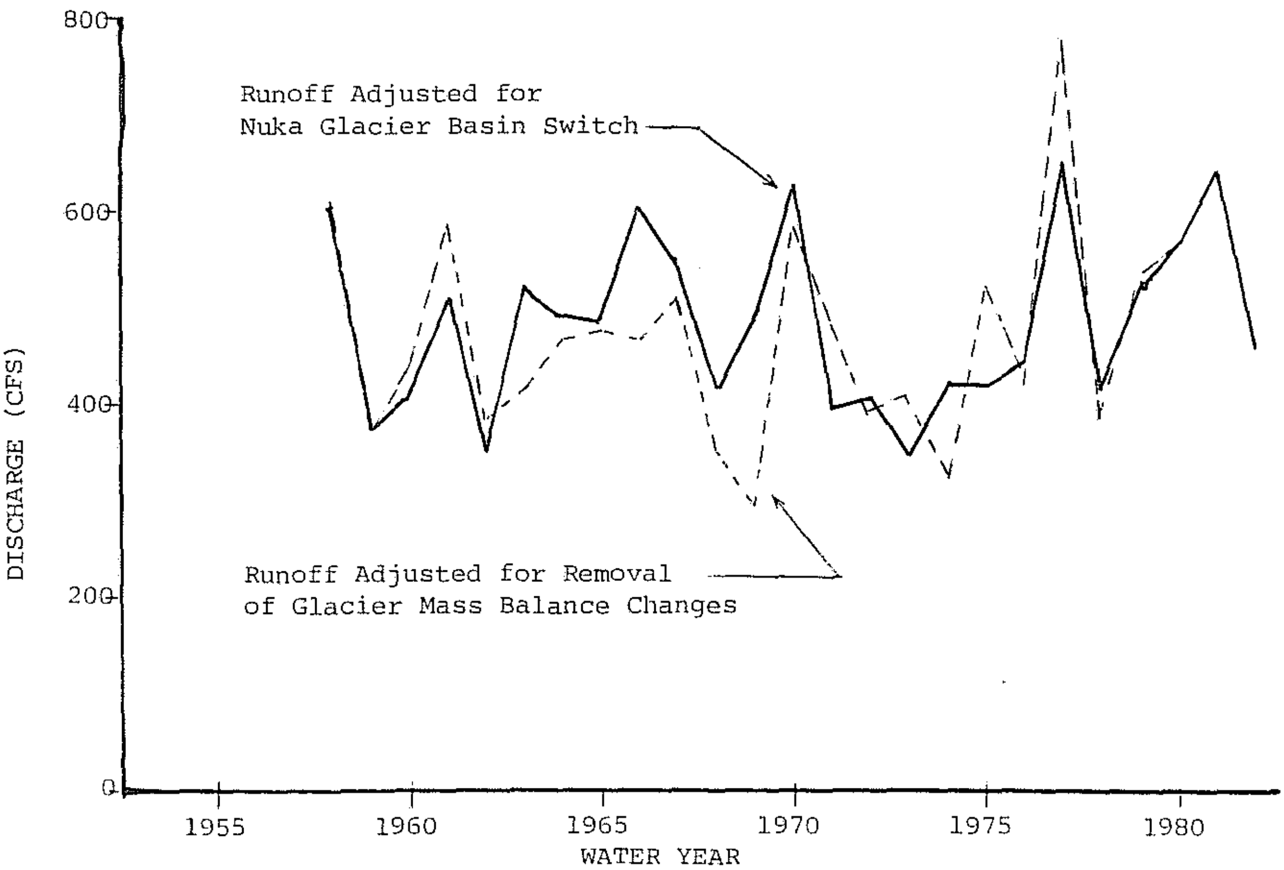

FIGURE 3 - Adjusted Annual Runoff, Bradley River

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ACKNOWLEDGEMENTS

We have been greatly aided by advice and information from abroad. We are especially grateful to G. Ostrem, H. Roethlisberger, and S. Omnanney.

RIVER PROCESSES

SCOUR DEPTH ESTIMATION IN GRAVEL BED RIVERS

by James W. Aldrich[1]

ABSTRACT

Scour coefficients to be used with the Lacey and Blench equations were derived from cross section information obtained in gravel bed rivers. Selection of a scour coefficient to calculate the scour depth in a bend was quantified by relating the scour coefficient to the type of bend, the bend severity, and the probability of occurrence. Scour in straight reaches was quantified by simply relating the scour coefficient to the probability of occurrence. The Lacey and Blench regime equations are discussed briefly and the assumptions inherent in the use of the scour coefficients are presented.

INTRODUCTION

The scour depth in a river is estimated in order to insure the integrity of structures such as pipelines, bridges and river training structures. Two of the more popular methods for estimating scour depth in rivers are those developed by Blench (1969) and Lacey (1930). Both methods involve the estimation of a "regime depth" or mean depth for a given flow, and use of a scour coefficient to convert the mean depth to the maximum scour depth. Unfortunately, little information is available to assist the user of the equations with determining a scour coefficient. Both authors have suggested broad ranges for the scour coefficients, but the actual value selected must be determined primarily based on the user's experience.

Since it is difficult to obtain the kind of experience necessary to reliably estimate scour coefficients, this study attempted to develop a quantitative method of estimating the coefficients. Although limitations in the available data will force the user of the equations to make certain assumptions, the quantitative techniques presented here for estimating the coefficients necessary to predict scour depth at bends and in straight reaches of gravel bed rivers should assist practicing hydrologists and engineers.

RIVER REGIME AND SCOUR ESTIMATION

A river that is "in regime," is one which does not change appreciably over a period of time. It is neither aggrading nor degrading, and is capable of adjusting its bed and banks to changes in discharge conditions. The condition of being "in regime" is analogous to being in a dynamic equilibrium. Thus, it is the average condition over a number

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of years which defines the regime condition.

Based on the idea that a channel in regime has certain properties which are a function of discharge and the material in which the river flows, both Lacey and Blench developed methods by which scour depth (or the maximum depth at a river cross section) could be determined. A detailed description of the development of the methods is given in Mobile-Bed Fluviology (Blench, 1969) and therefore, only a brief description of the methods will be given here. It should be noted that the regime concept started prior to Lacey's work and that methods other then those of Lacey and Blench have been developed. However, the Lacey and Blench methods are probably the most well known.

With regard to scour estimation, Lacey developed equations for regime velocity and hydraulic radius (Lacey, 1930), which by manipulation and approximation yielded the depth formula:

$$dm = 0.47(Q/f)^{0.33}$$

where: dm is Lacey's mean depth in feet (ft.), equal to cross-sectional area divided by water surface width, Q is discharge in cubic feet per second (cfs.), and f is Lacey's silt factor (note that silt, at the time Lacey was developing this factor, was synonymous with sediment).

Values for Lacey's silt factor (f) range from 0.4 for a bed of 200 mesh silt through 2 for a bed of "heavy sand" and 25 for "large boulders" (Lacey, 1934). Recommendations for estimating the maximum scoured depth were derived (by Lacey) by considering the shape of channel cross sections. Lacey (1930) stated that "in a river flowing through a stable reach the maximum depth should approximate to the mean depth multiplied by 1.273." The constant (1.273) was based on the assumption that the channel would have an elliptical cross-sectional shape in a straight reach. For moderate, severe and right-angled bends Lacey (1930) recommended multiplying the mean depth by 1.5, 1.75 and 2.0 respectively.

Blench's basic regime equations for the channel width and depth of a stable alluvial channel differ from Lacey's in the following respects. Width is defined as the width at half the depth, assuming a trapezoidal section. Depth is defined as the mean depth across the rectangular part of a trapezoidal section (or cross-sectional area divided by the width at half the depth).

The Blench mean depth (or regime depth) is given by the following formula (Blench, 1969):

$$dr = (q)^{0.67}/(Fb)^{0.33}$$

where: dr is regime depth in ft., q is discharge intensity at the design flood (cfs./ft.), Fb is the bed factor and is equal to Fbo(1+0.12C), C is the bed load charge in parts per hundred thousand, and Fbo is the zero bed factor. The zero bed factor is the bed factor when the bed load charge is zero and is a function of the size of the bed material and, depending on the situation, the regime depth (Blench, 1973).

In order to calculate the maximum scour depth to be used in designing aprons for river training structures, Blench (1969) suggests multiplying the regime depth by 1.7 for the most severe attack on a natural meander, and by a coefficient between 2.0 and 2.25 for an abrupt impingement of flow on a long bank. Once calculated, the maximum scour depth is then subtracted from the water surface of the design flood to obtain the minimum bed elevation.

T. Blench and Associates (1975) suggest that the maximum scour depth in braided streams be calculated from the bankfull stage. After the bankfull stage is reached in a braided river, the river stage does not rise significantly with increasing discharge and the flow is not concentrated within one distinct flow channel. Thus, the maximum scour depth probably occurs at bankfull stage. T. Blench and Associates also suggest that a scour coefficient between 1.4 and 4.0 be used to calculate the maximum scour depth in a forced bend, and that a scour coefficient between 1.4 and 2.5 be used to calculate the scour depth in a free eroding bend. A free eroding bend is defined as a bend which is free to erode laterally. A forced bend is defined as a bend in which the lateral erosion is at least partially limited due to the bank material being significantly coarser than the bed material.

Although both the Blench and Lacey regime equations were developed for sand bed rivers, both authors have suggested that their equations may be used to compute regime conditions in gravel bed rivers. Both authors have provided guidelines for the selection of the coefficients necessary for such calculations.

METHOD OF ANALYSIS

The data used for this analysis were taken from the reports of Doyle and Thompson (1979), Galay and Neill (1972), Neill (1973), and Nwachukwu and Neill (1972). The data were obtained on the Athabasca River, North Saskatchewan River and Oldman River in Alberta, Canada for the purpose of obtaining information on the depth of scour holes along each of the rivers.

The Blench scour coefficient was developed by dividing the maximum scour depth at a cross section by the reach-averaged Blench regime depth. The Blench regime depth was calculated with the zero bed factor. However, since the sediment concentration was estimated to be less than 0.01 parts per hundred thousand at most cross sections, the bed factor was essentially the same as the zero bed factor.

The scour constant, used in the Lacey equation, was developed by dividing the maximum scour depth in a bend by the reach-averaged Lacey mean depth. The Lacey mean depth was calculated as the cross-sectional area divided by the water surface width.

All depths used in the analysis of scour at bends and in straight reaches were calculated based on the dominant discharge or the bankfull stage. The stage used for the dominant or bankfull discharge was taken from the published reports (Doyle and Thompson, 1979; Galay and Neill, 1972; Neill, 1973; and Nwachukwu and Neill, 1972).

The data were used to develop separate scour coefficients for use with the Lacey and the Blench equations. The scour coefficients for use with a particular equation were then separated as to those pertaining to free eroding bends and those pertaining to forced bends, based on the comments of the authors of the original reports. Finally, the scour coefficients for use with a particular equation and a particular type of bend were regressed against a bend parameter.

Two parameters describing the bend were analyzed. The first consisted of the radius of curvature (in feet) divided by the deflection angle (in radians). The radius of curvature was measured from the center of the channel and the deflection angle was defined as the angle formed by the radius of curvature as it moved from the beginning of the bend to the end of the bend. The second bend parameter was the radius of curvature divided by the width times the deflection angle. The width was defined as the surface width at the cross section in the bend, at the discharge for which the depth was calculated.

In performing the regression analysis, each of the bend parameters and several transformations of the bend parameters were analysed in an attempt to develop a regression equation that could be used to estimate the scour coefficient. The transformations considered included 1/X, square root of X, X squared and the logarithm of X. The form of the bend parameter which produced the "best" regression equation was selected based on the coefficient of determination, the standard error of the estimate and the plausibility of the shape of the regression line. Once the "best" regression equation was selected the 90, 95 and 99 percent confidence limits were calculated (Volk, 1982).

RESULTS

Scour In Straight Reaches

The average Blench scour coefficient obtained from the analysis of 73 cross sections was 1.1, and the standard deviation was 0.24. Of the 73 Blench scour coefficients calculated for straight reach cross sections, 29 were less than or equal to 1.0. The largest Blench scour coefficient was 1.8. Two scour coefficients were equal to or greater than 1.7 and eight cross sections had Blench scour coefficients equal to or greater than 1.5.

Within a homogeneous reach, the average variation in the Blench mean depth was 14.8 percent. The maximum average variation within any of the 13 reaches (on 3 rivers) studied was 30.8 percent.

The average Lacey scour coefficient obtained from the analysis of 73 cross sections was 1.4, and the standard deviation was 0.34. Of the 73 Lacey scour coefficients calculated for straight reach cross sections, 3 were less than or equal to 1.0. The largest Lacey scour coefficient was 2.7, and four scour coefficients were equal to or greater than 2.2.

Within a homogeneous reach, the average variation in the Lacey mean depth was 11 percent. The maximum variation within any of the 13 reaches (on 3 rivers) studied was 23 percent.

Scour At Bends

After considering the correlation coefficient, the standard error of the estimate and the plausibility of the shape of the curve developed from each transformation of each of the bend parameters, the square root of the radius of curvature divided by the deflection angle seemed to produce the most satisfactory bend parameter for each of the regression equations. Regression equations were developed for four types of scour coefficients: the Blench scour coefficient for forced bends, the Lacey scour coefficient for forced bends, the Blench scour coefficient for free bends and the Lacey scour coefficient for free bends.

The equation which best described the relationship between the Blench scour coefficient and the bend severity at forced bends is given by:

$$Z = 3.24 - 0.64(Rc/A)^{0.5}$$

where: Z is the scour coefficient, Rc is the radius of curvature in feet, and A is the deflection angle in radians. The coefficient of determination is 0.53 and the standard error of the estimate is 0.48. The data, and the 50, 90, 95 and 99 percent confidence limits are shown in Figure 1.

The equation which best described the relationship between the Lacey scour coefficient and the bend severity at forced bends is given by:

$$Z = 3.88 - 0.82(Rc/A)^{0.5}$$

where all of the parameters are as described above. The coefficient of determination is 0.42 and the standard error of the estimate is 0.73. The data, and the 50, 90, 95 and 99 percent confidence limits are shown in Figure 2.

The equation which best described the relationship between the Blench scour coefficient and the bend severity at free bends is given by:

$$Z = 2.18 - 0.021(Rc/A)^{0.5}$$

where all of the parameters are as described above. The coefficient of determination is 0.082 and the standard error of estimate is 0.44. The data, and the 50, 90, 95 and 99 percent confidence limits are shown in Figure 3.

FIGURE 1. BLENCH SCOUR COEFF. FOR FORCED BENDS

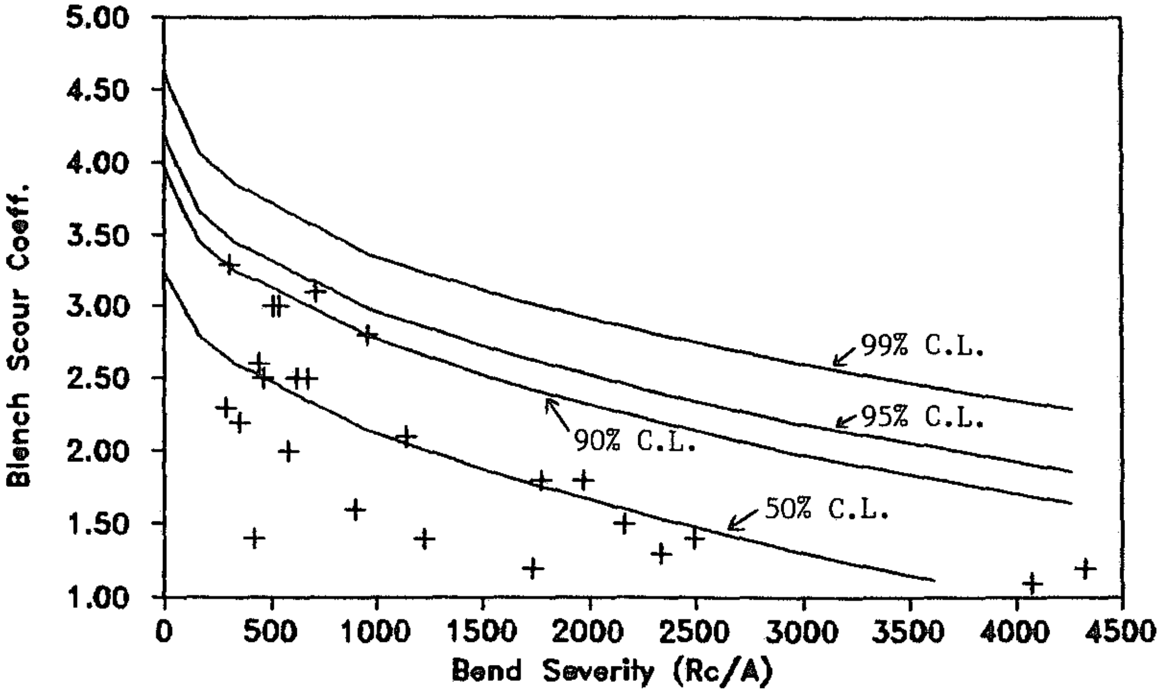


FIGURE 2. LACEY SCOUR COEFF. FOR FORCED BENDS

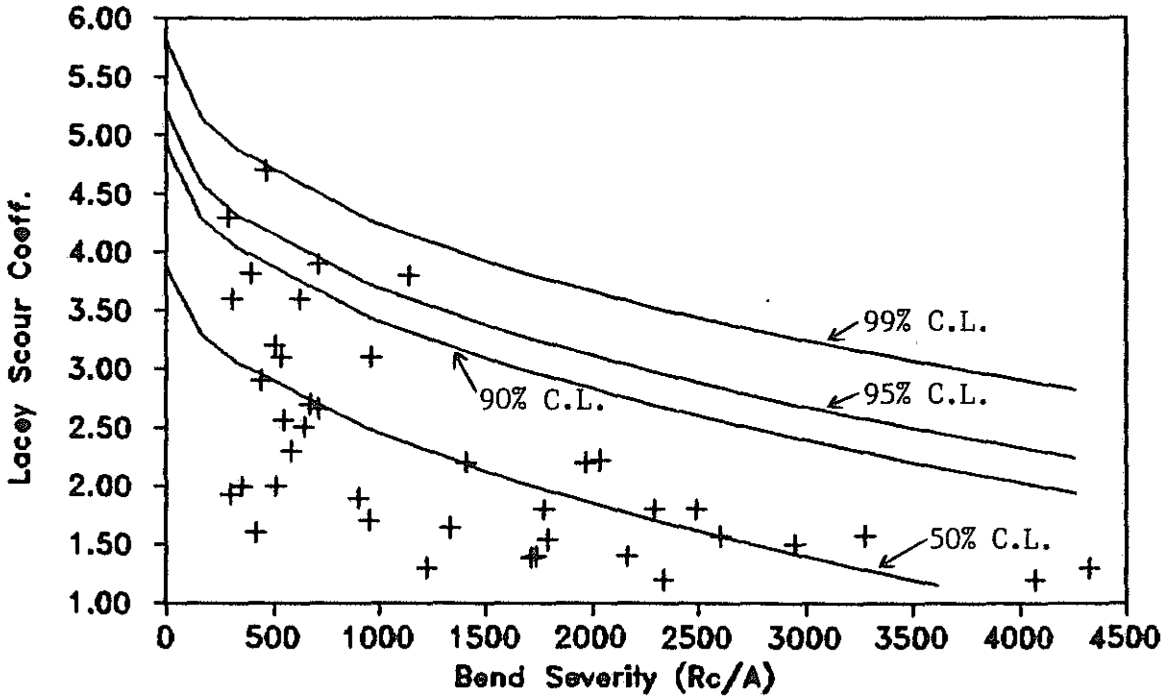


FIGURE 3. BLENCH SCOUR COEFF. FOR FREE BENDS

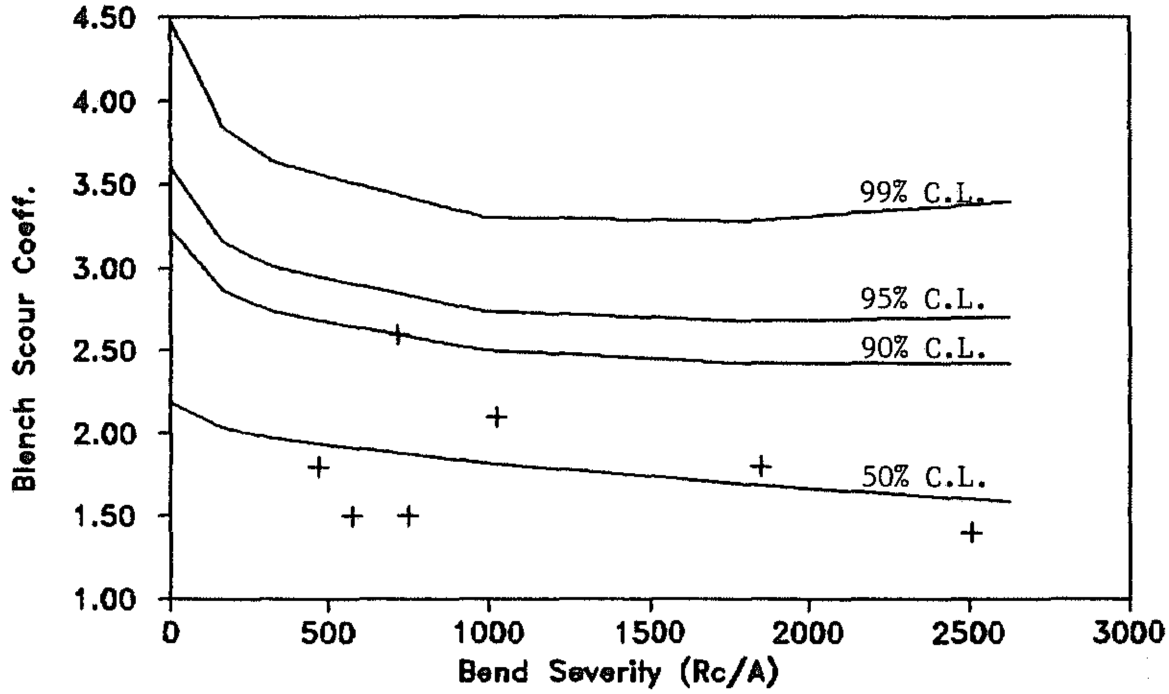
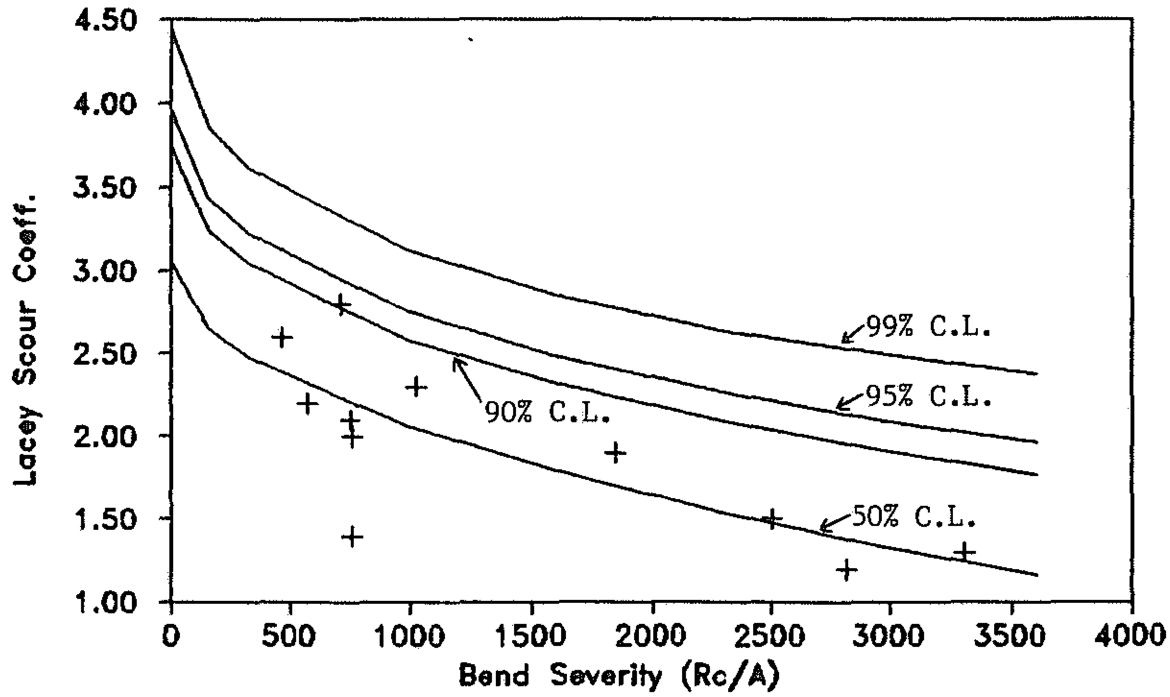


FIGURE 4. LACEY SCOUR COEFF. FOR FREE BENDS



Finally, the equation which best described the relationship between the Lacey scour coefficient and the bend severity at free bends is given by:

$$Z = 3.05 - 0.057(Rc/A)^{0.5}$$

where all of the parameters are as described above. The coefficient of determination is 0.58 and the standard error of the estimate is 0.37. The data, and the 50, 90, 95 and 99 percent confidence limits are shown in Figure 4.

DISCUSSION

Although the scour data were not collected during the flood that produced the measured scour holes, the scour holes are considered to be representative of the magnitude of scour produced during a bankfull or dominant discharge. It has been shown (Galay and Neill, 1972) that the scour holes on the North Saskatchewan River (from which most of the data for this analysis came) did not fill with the passage of medium size floods. Since the scour holes are probably the result of medium size floods, and since the bankfull or dominant discharge on all of these rivers is a medium size flood, it is assumed that the scour depth data represents the magnitude of scour that would occur during a bankfull or dominant discharge flood.

Scour In Straight Reaches

The selection of a scour coefficient for the prediction of scour depth in straight reaches can be quantified by considering the probability of occurrence. If the scour coefficient at the 99 percent confidence level is used, there will be a 1 percent chance that the actual scour depth will be greater than the estimate. If the scour coefficient at the 95 percent confidence level is used, there will be a 5 percent chance that the actual scour depth will be greater than the estimate. Thus, the following scour coefficients might be used for predicting the scour in a straight reach, depending upon the acceptable risk.

Blench scour coefficient:	
1 percent chance of being equalled or exceeded	1.7
5 percent chance of being equalled or exceeded	1.5
50 percent chance of being equalled or exceeded	1.1
Lacey scour coefficient:	
1 percent chance of being equalled or exceeded	2.2
5 percent chance of being equalled or exceeded	2.0
50 percent chance of being equalled or exceeded	1.4

An appreciation for the conditions representing the boundary between straight reaches and bends can be obtained from Figures 1, 2, 3 and 4. The point at which the average scour coefficient for straight reaches equals the average scour coefficient for a bend defines the approximate boundary between bends and straight reaches. From the data presented in the figures it appears that cross sections at which Rc/A is greater than 3900 should be considered straight reaches.

The maximum variation in the mean depth within straight reaches is of interest in determining the amount of error that might be introduced by calculating the reach-averaged mean depth based on only one cross section in a straight reach. For example, the maximum average variation in calculating the Blench mean depth was 30 percent. Thus, it is quite likely that in some reaches if an estimate of the reach-averaged mean scour depth is made using only one cross section, the estimate could be in error by more than 30 percent. If this value of the reach-averaged mean depth was then used to calculate a maximum scour depth, the maximum scour depth would also be in error by a similar amount. Thus, the need to determine the reach-averaged mean depth based on a number of cross sections taken in straight reaches is apparent.

Scour At Bends

For estimating scour in a forced bend it appears that the regression equations developed for the Blench scour coefficient and the Lacey scour coefficient fit the bend parameter equally well. For estimating scour in a free bend the regression equation developed for the Lacey scour coefficient appears to fit the bend data considerably better than did the Blench scour coefficient. The difference may be related to the fact that there was considerably more data available with which to develop the regression equation for the Lacey scour coefficient.

Although Figures 1, 2, 3 and 4 all show the "best-fit" regression line, for design purposes the estimate given by the "best-fit" line would normally not be satisfactory. Use of a scour coefficient estimated from the "best-fit" line would mean that about 50 percent of the time the estimated scour depth would be less than the actual scour depth. Thus, the 90, 95 and 99 percent confidence limits have been added to the figures.

At an Rc/A of approximately 160 (about half that of the most severe bend in the data set) the 99 percent confidence line corresponds to a value of approximately 4 for the Blench scour coefficient (Figure 1). This is about the same value as suggested by T. Blench & Associates (1975) as the maximum Blench scour coefficient for forced bends in braided rivers, with the scour depth measured from bankfull stage. The minimum scour coefficient suggested by T. Blench & Associates (1975) was 1.4 and corresponds to a bend severity of approximately 3000. Since most of the bends analysed were more severe than that represented by a bend severity of 3000, it is felt that the range of scour coefficients suggested in Figure 1 agree fairly well with the experience of other authors.

The scour coefficients for use with the Lacey equation are generally greater than those suggested by Lacey because a reach-averaged mean depth was used in the calculation. Had the scour coefficient been developed considering the surface width at the bend for which the scour was being estimated, the results would have been much closer to those suggested by

Lacey (1930). However, for most design work scour coefficients based on the reach-averaged mean depth are probably more useful.

Finally, if the measured scour holes truely represent those formed during the bankfull discharge, it should be possible to transfer the scour coefficients developed in this study to other flood magnitudes. Thus, the design water surface elevation may be estimated for a particular project and the expected scour depth estimated using the scour coefficients developed herein. It should be noted, however, that the three "best" regression equations presented explain only 42 to 58 percent of the variability in the data. Thus, although the equations do assist in quantifying the selection of a scour coefficient, more work is needed in order to develop equations which explain more of the natural variability.

SUMMARY

A quantitative method of determining the scour coefficients for use with the Blench and Lacey regime equations was developed. The scour coefficients for use in straight reaches are based on the probability of occurrence. The scour coefficients for use in predicting scour depth at bends are based on the type of bend (free or forced), the severity of the bend and the probability of occurrence. Useful equations were developed to predict the Blench scour coefficient for forced bends, the Lacey scour coefficient for forced bends and the Lacey scour coefficient for free bends. Although some important assumptions were necessary in order to use the available data, and although the best regression equations only explained 42 to 58 percent of the variability of scour depth in bends, Figures 1, 2 and 4 can be used to help quantify the selection of a scour coefficient for use in calculating scour depth at bends.

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FLOW ESTIMATES

VARIABILITY OF FLOOD ESTIMATES BASED ON RECORD LENGTH
FOR SELECTED ALASKAN RIVERS

William S. Ashton[(1)]

ABSTRACT

With the sparse data base of streamflow records in Alaska, hydrologists need to maximize the use of existing data. For flood frequency analyses the U.S. Water Resource Council recommends using a minimum of ten years of streamflow data. In Alaska, this has been reduced to five years for some analyses. The variability of the estimated flood magnitude associated with record lengths is quantified using data from nine gaging stations with thirty years or more of continuous record. For each station the period of continuous record was divided into shorter record lengths of: three 10-year, and six 5-year records for a total of ten records for each station. The lognormal distribution was used to compute flood magnitudes with recurrence intervals of 1.25-, 2-, 5-, 10-, 20-, 50- and 100-years for each station record. The "short" records were compared with the thirty year records to quantify the variability associated with each record length. For all stations, the ten year records provided estimates of flood magnitudes closer to the thirty year record than the five year records by 8 to 50 percent for the 100-year flood.

INTRODUCTION

Hydrologists often need to know the flood magnitudes of streams and rivers. The recurrence intervals selected are typically 2-, 20-, 50- and 100-years. The longer the period of record of streamflow data used to estimate the flood magnitudes, the lower the associated error of estimate. For example, to be able to estimate the 50 year flood with 25 percent accuracy 80 percent of the time, 15 years of record are required whereas 90 years of record are needed to come within 10 percent of the 50 year flood 80 percent of the time (Benson, 1960). Therefore to improve the flood estimate the hydrologist wants to use the longest available period of record.

Regionalizing, or grouping, of streamflow data is one means of estimating flows from ungaged basins. The error associated with regional flood frequency equations is a function of, among other considerations, the record length of the stations selected and the number of stations used in the regionalization. Typically, a minimum of ten years of record is required at a station to use it for flood frequency analyses (US Water Resource Council, 1982). In Alaska (as of 1983) there are 136 stations with 10 years or more of stream flow record and 192 stations with 5 years or more of stream flow record (Lamke, 1984). The distribution of the stations around the state is skewed towards southeast and south-central Alaska. Of stations with 10 years or more of record, 48 are in southeast

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Alaska and 50 in south-central Alaska with only 38 stations for the remainder of the state. Of stations with 5 years or more of record, the distribution is 72, 63, and 57 stations in southeast, south-central, and the remainder of Alaska, respectively. To maximize the use of the existing record, recent regional analyses for Alaska have reduced the recommended minimum of ten years of record to five years (Lamke, 1979; OTT Water Engineers, 1979; State Pipeline Coordinator, 1981; and Ashton and Carlson, 1984). It must be determined whether the increased error associated with the shorter record lengths is less than the reduction in error due to the increase in the number of stations used in the analyses. The following discussion examines the first part of this question - the variability associated with record length. Streamflow records from nine gaging stations with more than thirty years of record were used to quantify the variability of flood magnitudes associated with the "short" records.

METHODS

U.S. Geological Survey gaging stations with 30 years or more of annual instantaneous peak flows were initially selected. If a station had a break in the record of two years or less the missing record was estimated using nearby stations to estimate the missing value(s). If stations had breaks in the record of three years or more, or if there was no nearby stations to correlate flows with, the station was deleted from further consideration. No station records were extended to obtain thirty years of record. Flood magnitudes were computed using the lognormal distribution because it can provide more sensible results for gaging stations with short periods of record than three parameter distributions (Flood Studies Report, 1975), and has been shown to provide as reasonable results as the log-Pearson Type III distribution (Beard, 1974). Stations with outliers were identified using techniques according to the U.S. Water Resources Bulletin 17B (1982). Station records were split into one 30-year, three 10-year and six 5-year records. The starting point for all "short" records were selected using a random number to designate the start of the thirty year record. Ratios were computed for the flood magnitudes from the 5 and 10 year records to the 30 year record. The ratios were examined to define the variability associated with "short" records.

DISCUSSION

Split record analysis of existing stream flow records provides a means of quantifying the variability of flood estimates associated with different lengths of record. Nine gaging stations were selected for this analysis (Table 1). Two stations, Little Susitna River near Palmer and Fish Creek near Ketchikan, were retained even though they had outliers, so that the effect of the outliers could be examined. Figures 1 through 9 show the range of frequency curves from the split record analysis. Table 2 shows the range of ratios for the 5- and 10-year records.

The 10-year records provide flood estimates closer to the flood estimates using the 30-year records than the flood estimates using the 5-year records. Examining individual stations shows the 5-year record can

TABLE 1 USGS Continuous Streamflow Gaging Stations Selected for This Report

Station Number	Station Name	Drainage Area Sq. Mile	Period of Record	Period of Record Used in this Analysis
15022000	Harding River near Wrangell	67.4	1951-	1952 - 1981
15050000	Gold Creek at Juneau	9.76	1916-20, 46-48, 49-	1953 - 1982
15072000	Fish Creek near Ketchikan	32.1	1915-36, 38-	1940 - 1969
15085100	Old Tom Creek near Kassan	5.9	1949-	1952 - 1981
15216000	Power Creek near Cordova	20.5	1947-	1950 - 1979
15290000	Little Susitna River near Palmer	61.9	1948-	1951 - 1980
15292000	Susitna River at Gold Creek	6,160	1949-	1952 - 1981
15356000	Yukon River at Eagle	113,500	1911-13, 50-	1952 - 1981
15476000	Tanana River near Tanacross	8,550	1953 -	1953 - 1982

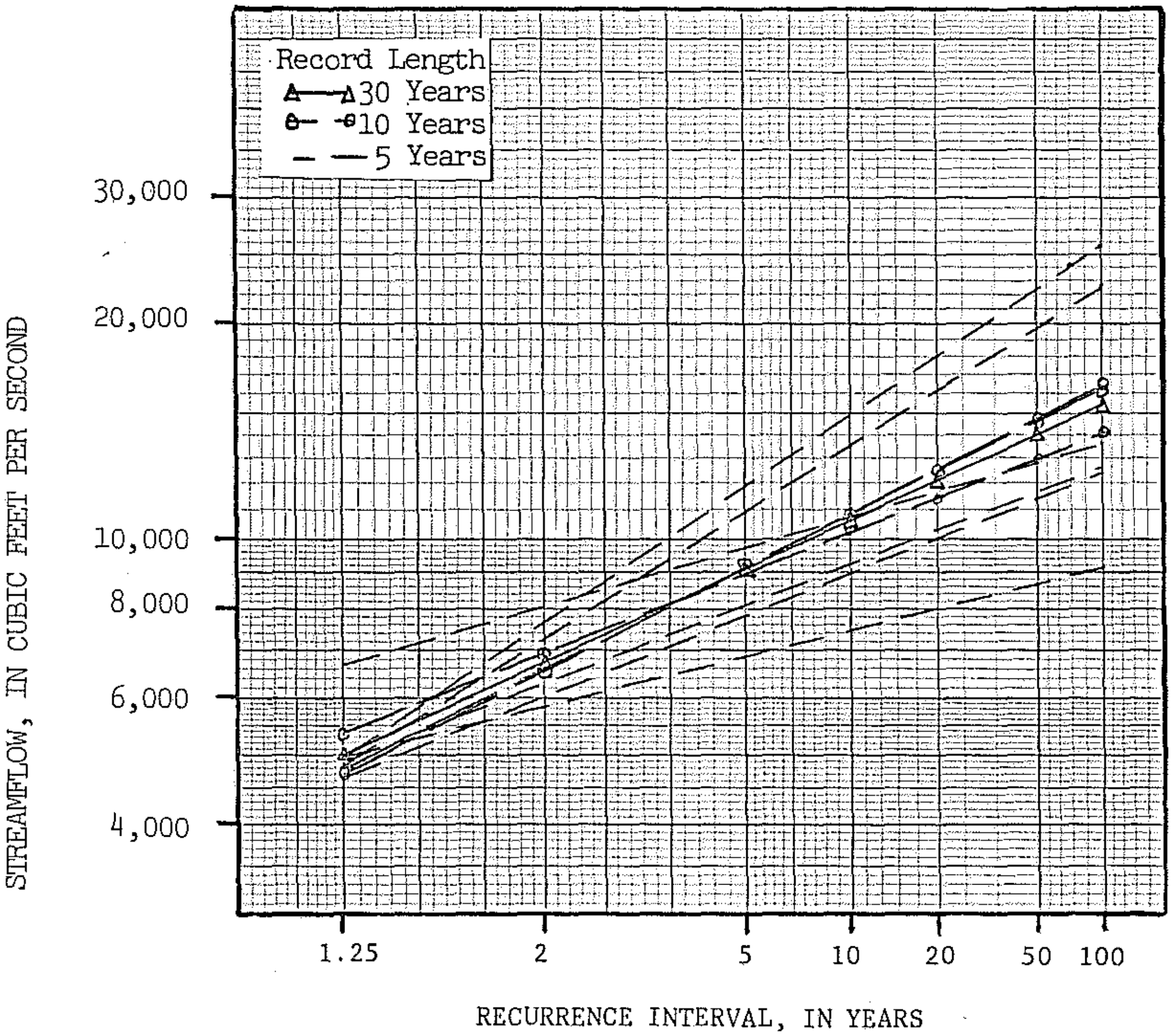

Figure 1. Flood-Frequency curve for the Harding River near Wrangell, Station number 15022000

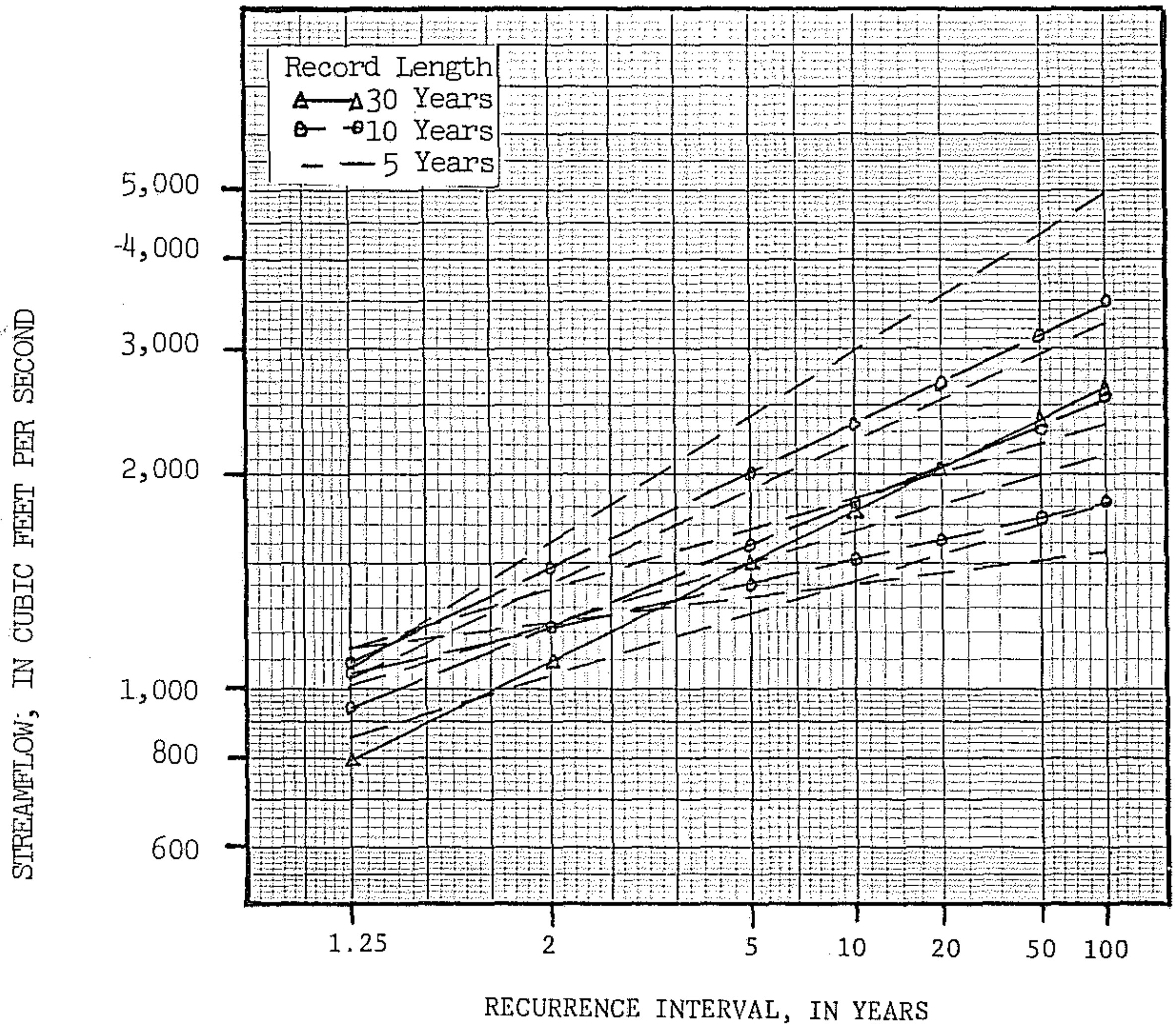

Figure 2. Flood-Frequency curve for Gold Creek at Juneau, Station number 15050000

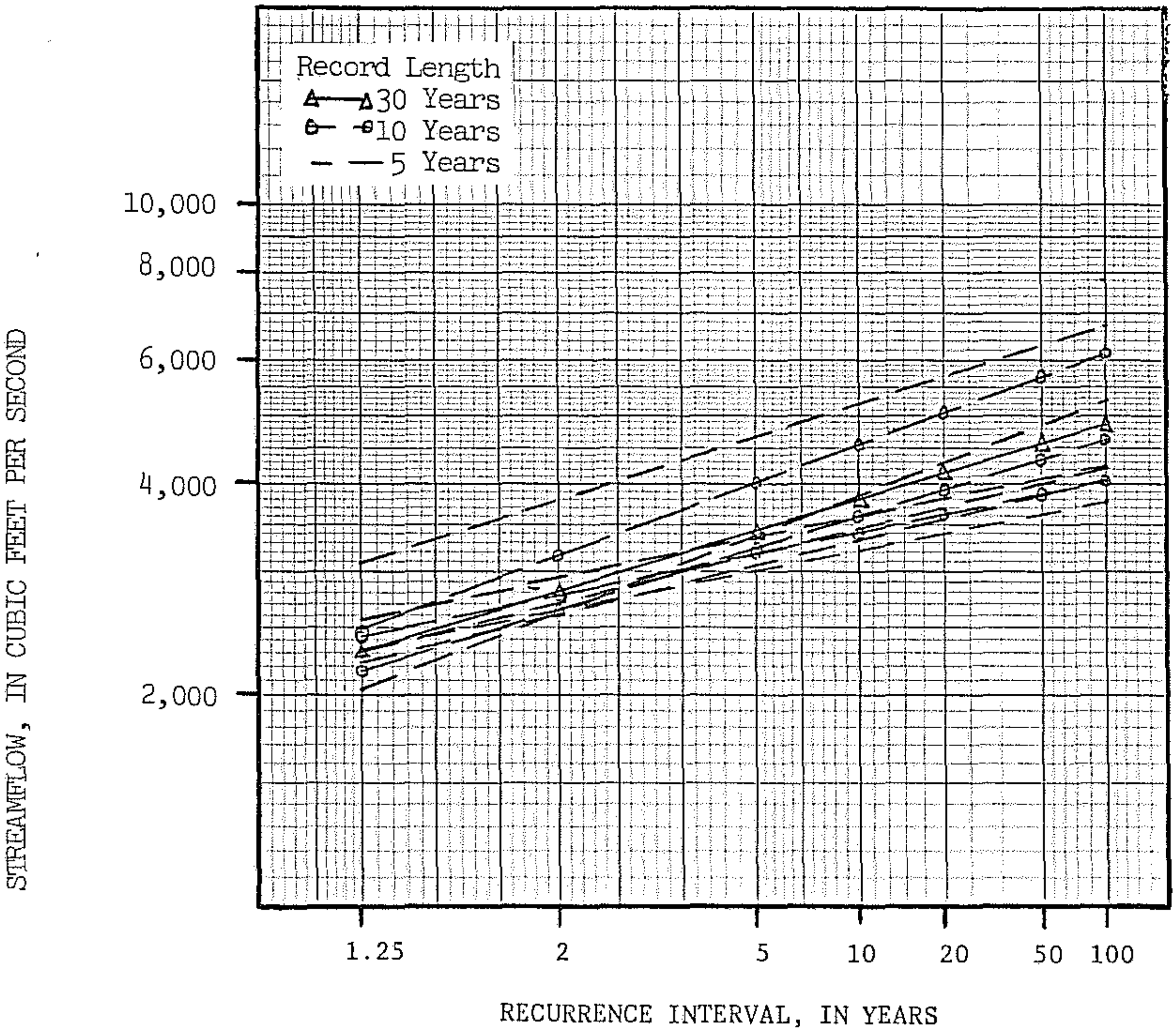

Figure 3. Flood-Frequency curve for Fish Creek near Ketchikan, Station number 15072000

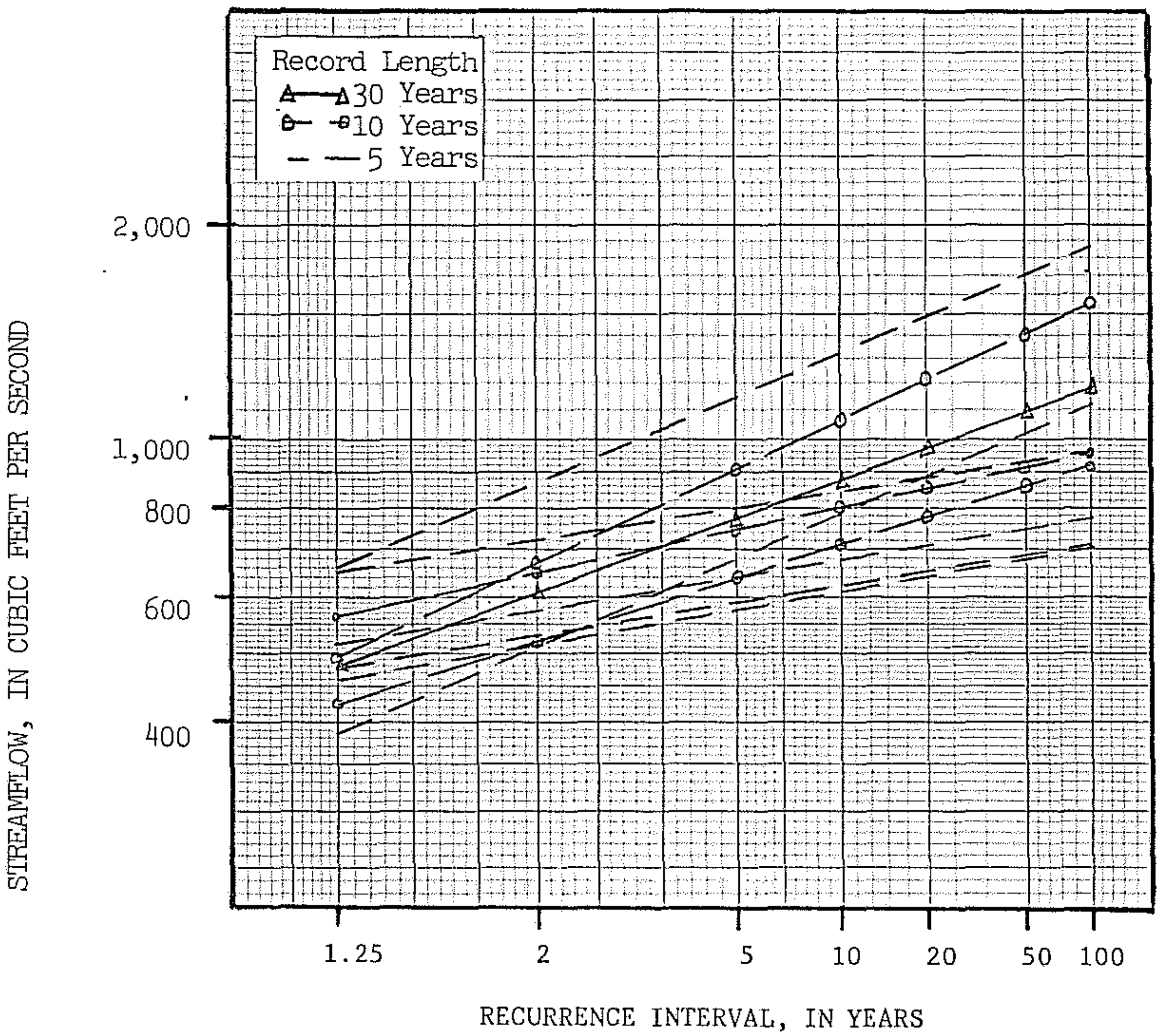

Figure 4. Flood-Frequency curve for Old Tom Creek near Kassan, Station number 15085100

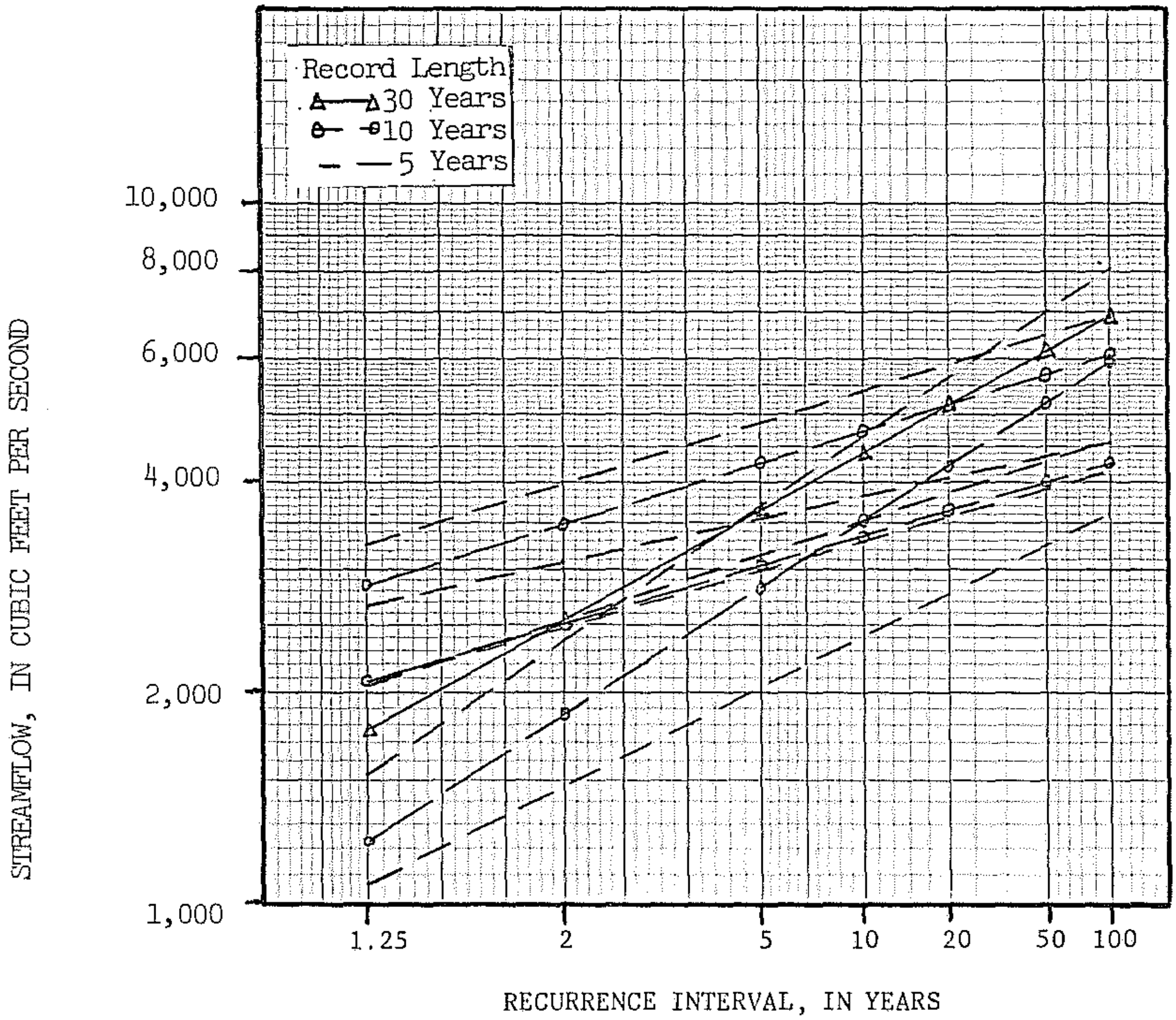

Figure 5. Flood-Frequency curve for Power Creek near Cordova, Station number 15216000

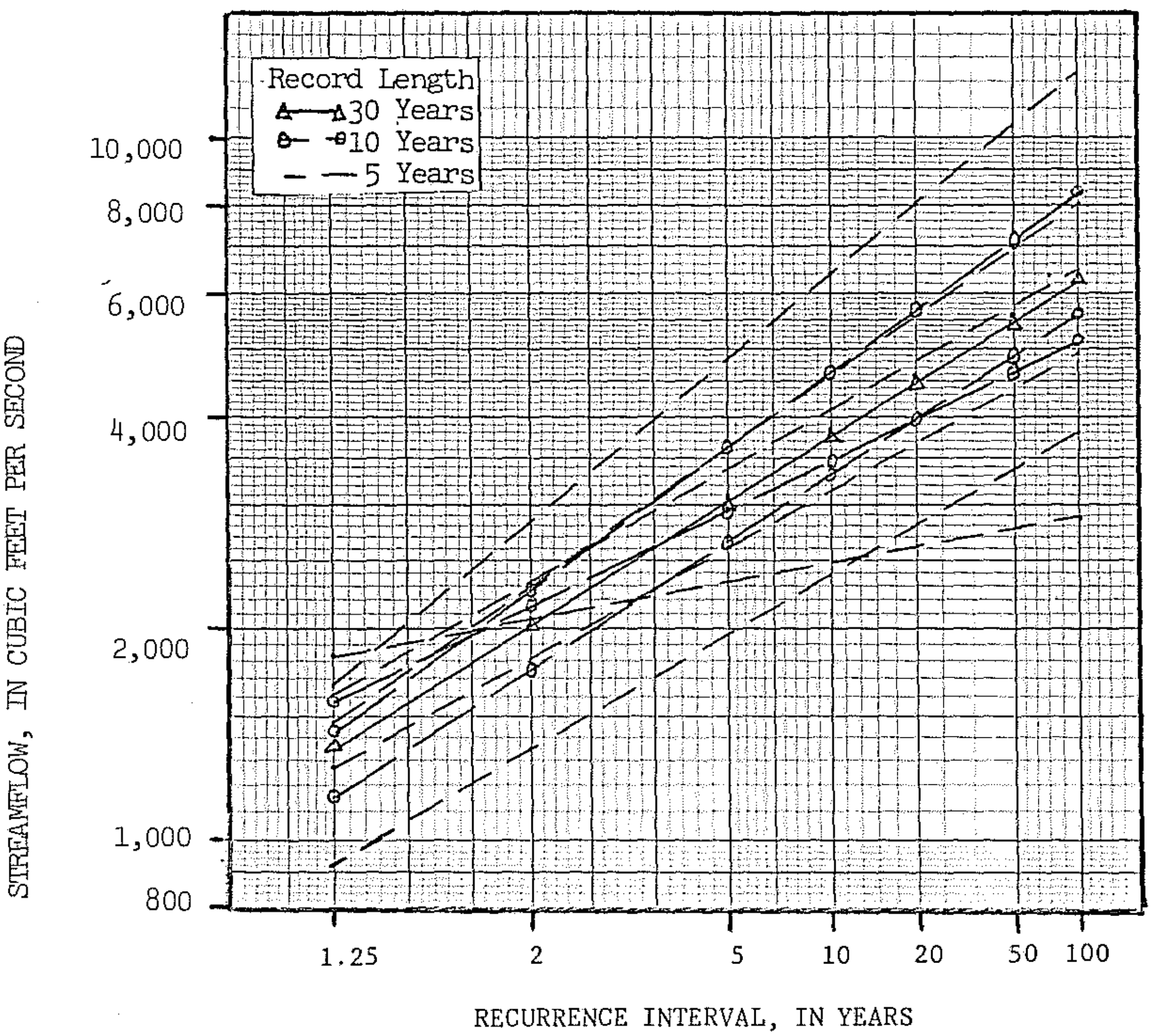

Figure 6. Flood-Frequency curve for the Little Susitna River near Palmer, Station number 15290000

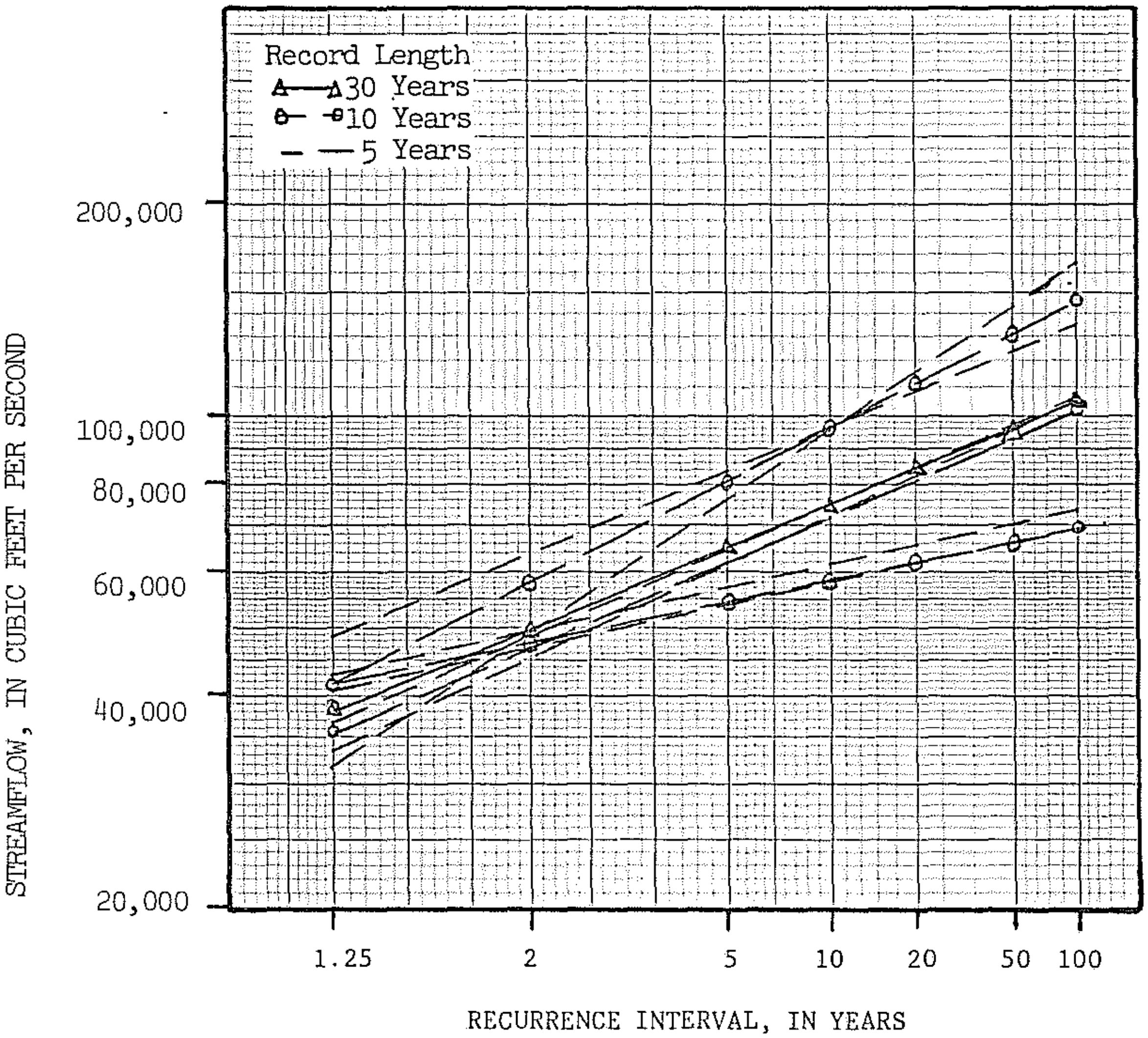

Figure 7. Flood-Frequency curve for the Susitna River at Gold Creek, Station number 15292000

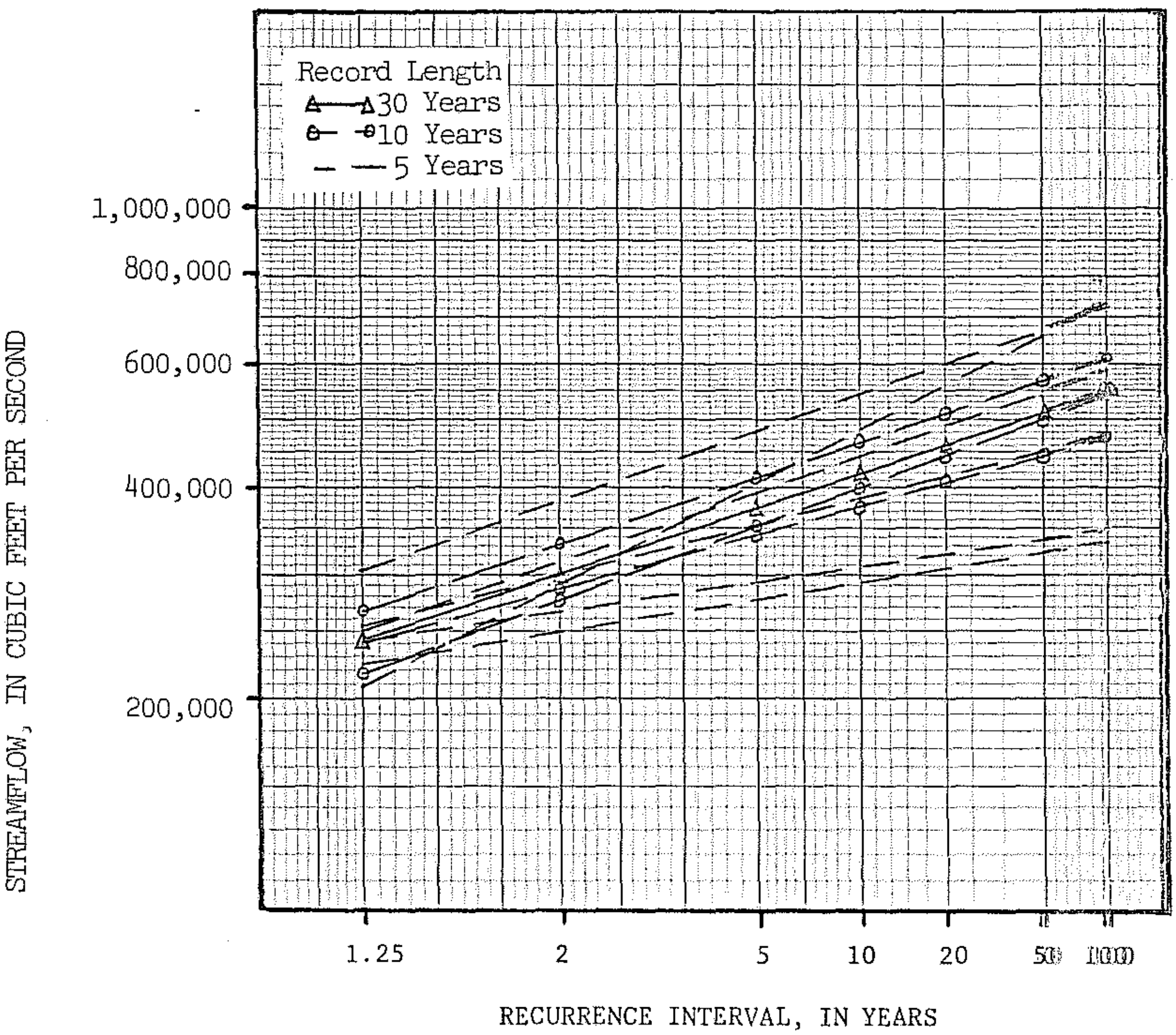

Figure 8. Flood-Frequency curve for the Yukon River at Eagle, Station number 15356000

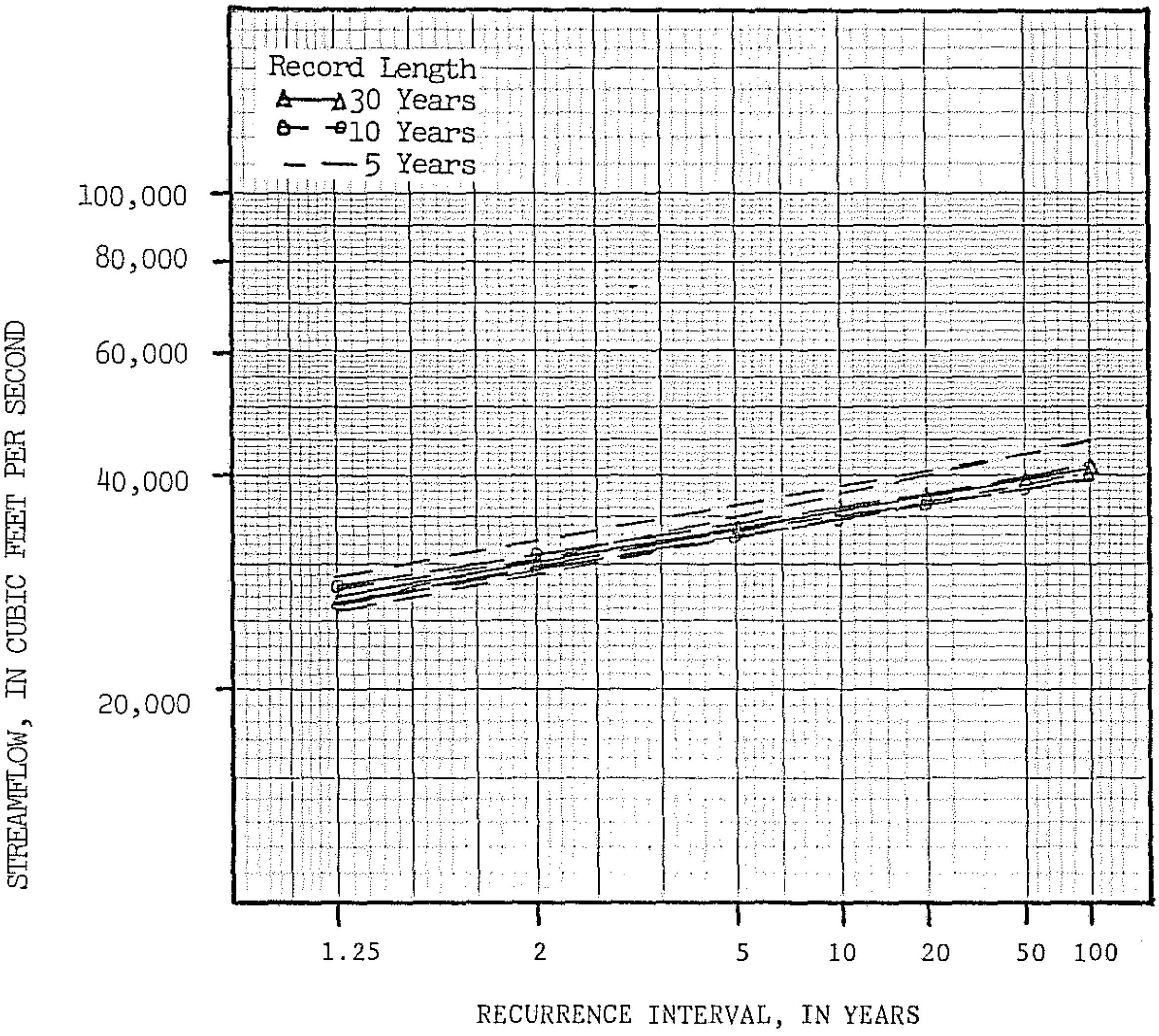

Figure 9. Flood-Frequency curve for the Tanana River near Tanacross, Station number 15476000

TABLE 2 Range of Ratios of Flood Values Estimated Using Five and Ten Year Records to Flood Values Estimated Using Thirty Year Record

Station Number	Return Period (Years) 1.25		2.0		5		10		20		50		100	
	5	10	5	10	5	10	5	10	5	10	5	10	5	10
15022000	0.92 - 1.34	0.95 - 1.08	0.86 - 1.20	0.98 - 1.03	0.76 - 1.30	0.99 - 1.02	0.71 1.40	0.96 - 1.05	0.66 1.49	0.94 - 1.06	0.62 1.59	0.92 - 1.07	0.60 1.67	0.91 - 1.07
15050000	0.85 - 1.13	0.91 - 1.08	0.94 1.23	0.92 - 1.14	0.76 - 1.43	0.84 - 1.20	0.73 1.55	0.79 - 1.24	0.68 - 1.66	0.75 - 1.26	0.70 - 1.79	0.72 - 1.30	0.59 1.88	0.69 1.32
15072000	0.87 1.11	0.94 - 1.06	0.84 - 1.05	0.90 - 0.99	0.81 - 0.99	0.86 - 0.95	0.76 1.01	0.84 - 0.95	0.78 1.04	0.82 - 0.95	0.77 - 1.07	0.80 - 0.96	0.76 - 1.09	0.79 0.96
15085100	0.80 - 1.36	0.89 - 1.17	0.84 - 1.44	0.85 - 1.10	0.74 - 1.49	0.82 - 1.18	0.70 1.52	0.81 - 1.22	0.66 - 1.53	0.79 - 1.25	0.62 - 1.56	0.78 - 1.30	0.59 1.58	0.77 - 1.33
15216000	0.60 - 1.84	0.69 - 1.61	0.58 - 1.57	0.73 1.38	0.56 - 1.35	0.78 1.18	0.55 1.24	0.76 - 1.09	0.54 1.16	0.71 - 1.02	0.53 1.15	0.66 - 0.94	0.53 - 1.18	0.62 - 0.89
15290000	0.68 - 1.33	0.84 - 1.15	0.66 - 1.38	0.85 - 1.11	0.64 - 1.58	0.87 - 1.19	0.63 - 1.69	0.88 - 1.23	0.57 - 1.79	0.88 1.27	0.50 1.90	0.84 - 1.31	0.46 - 1.99	0.82 - 1.34
15292000	0.83 1.27	0.93 1.10	0.93 - 1.26	0.94 1.11	0.81 - 1.25	0.84 - 1.12	0.76 - 1.24	0.78 - 1.26	0.72 - 1.33	0.73 - 1.31	0.67 1.44	0.69 - 1.36	0.64 1.52	0.66 - 1.40
15356000	0.92 1.24	0.91 - 1.04	0.82 1.26	0.93 1.12	0.74 - 1.28	0.92 1.12	0.70 - 1.29	0.90 1.12	0.66 - 1.30	0.89 1.12	0.63 1.31	0.87 - 1.12	0.61 1.34	0.86 - 1.12
15476000	0.96 - 1.06	0.97 - 1.04	0.97 - 1.07	0.99 - 1.04	0.97 - 1.08	0.99 - 1.03	0.97 - 1.08	0.98 - 1.02	0.97 - 1.07	0.97 - 1.02	0.96 - 1.07	0.96 - 1.01	0.95 - 1.07	0.95 - 1.00

provide reasonable flood estimates. The 5-year records of Tanana River at Tanacross, for example, provide flood estimates nearly as good as the 10-year records (Figure 9). The range of ratios for the 5-year records to the 30-year record is 0.95 to 1.07, for the 10-year records the ratios are 0.95 to 1.00 (Table 2).

The longer record length improves the flood estimates for high probability events as well as low probability events. The 2-year flood is used in the design of culverts for fish passage (Anonymous, 1980), and it approximates bank full stage (Leopold, Wolman and Miller, 1964). For the 5-year records, the range of ratios of the 5-year record 2-year flood to the 30 year record 2-year flood is 0.58 to 1.57. The range of ratios is 0.73 to 1.38 for the same flood event using 10 years of records. Although 10 years of record improve the estimate, there is still considerable variability in the estimate. Some engineering analyses use 5 years of record to estimate the 100-year flood although the recommended minimum record length to use is 22 years (Lamke, 1979). Since many areas of the state lack any record, the tendency is to use any available record. Examining Figures 1 through 9 and Table 2 provides the hydrologist with a better understanding of the variability associated with various record lengths.

Outliers are extreme flood events which depart from the trend of a data set. With 30 years of record there may be no outliers. However, "short" records selected from this period of record may have outliers. With only 5 to 10 years of streamflow data, it is difficult to define the trend of the data. Therefore, the tendency is to retain outliers. Besides the effect of outliers, large variability in the flood estimate could be related to climatological factors such as dry periods and wet periods. Power Creek near Cordova has no outliers, but has the greatest range in ratios for the 1.25- and 2-year flood (Table 2). One 5-year "record", 1955 to 1959, had the first, second, third, tenth and fourteenth largest events, and was followed by a five year "record", 1960 to 1965, with the thirteenth, twenty sixth, twenty seventh, twenty eighth and thirtieth largest events. This wet period followed by a dry period produced widely varying flood estimates. Little Susitna River near Palmer(Figure 6) illustrates the effect of an outlier during the 30-year period of record. This station has the greatest range in ratios for the 5-year records for the 5-, 10-, 20-, 50- and 100-year flood events. Susitna River at Gold Creek is an example of a station with no outliers in the 30-year record, but it has outliers in the 5-year records (Figure 7).

SUMMARY

The variability associated with record length is quantified for nine stations in Alaska. These results illustrate the range in values which can be expected with short record lengths. For recurrence intervals of 1.25-, 2-, and 5-years, the 10-year records provide significantly better flood estimates than the 5-year records. For some stations the 5-year records can provide reasonable estimates (within 10 percent of the 30-year record) for the 100-year flood. This, however, is not known until there is 30 years of record. For some stations, such as Fish Creek near Ketchikan and

Tanana River at Tanacross, the 5-year records provide 100-year flood estimates nearly as good as the 10-year records.

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ESTIMATING ANNUAL MEAN AND 7-DAY 10-YEAR LOW-FLOW DISCHARGES FOR PARTIAL-RECORD STATIONS IN THE LOWER KENAI PENINSULA, ALASKA

by Charles S. Savard[1]

ABSTRACT

Estimates of annual mean discharge at 39 partial-record stations in the lower Kenai Peninsula are based on periodic measurements made during a 12-month period, and range from 2.2 to 297 cubic feet per second. A verification using a gaging-station record as if it were a partial-record site shows the method to estimate within 6 percent of the mean annual discharge.

Estimates of 7-day 10-year low-flow discharges at the 39 partial-record stations range from 0.03 to 0.69 cubic feet per second per square mile. An ordinary least squares regression model is computed using the baseflow discharges of a partial-record station and concurrent mean daily discharges of an index gaging station. The estimated 7-day 10-year low-flow discharge is computed from the index gaging station 7-day 10-year low-flow discharge and the regression model.

INTRODUCTION

To make decisions regarding the use and protection of surface-water resources, planners and designers need reliable information on streamflow characteristics. In July 1978, the U.S. Geological Survey, in cooperation with the Kenai Peninsula Borough, began a general, area-wide appraisal of the surface-water resources of the lower Kenai Peninsula (Savard and Scully, 1984). Part of the appraisal consisted of using discharge data, collected in 1978-80 at 39 partial-record stations, in conjunction with streamflow data for 3 long-term continuous gaging stations, to estimate the annual mean and the 7-day 10-year low-flow discharge at each partial-record site.

The study area, exclusive of the small basins near Seldovia, is bordered on the south and southeast by Kachemak Bay, on the west by Cook Inlet, on the north by the Kasilof River and Tustumena Lake, and on the east by the Fox River (fig. 1). The area is approximately 22 mi wide and 38 mi long (about 700 mi^2). The northwest part of this area is generally less than 500 ft above sea level. The drainage is poorly defined, and the hummocky surface is mostly marshes and muskeg areas. In contrast the southeast part of this area rises to altitudes between

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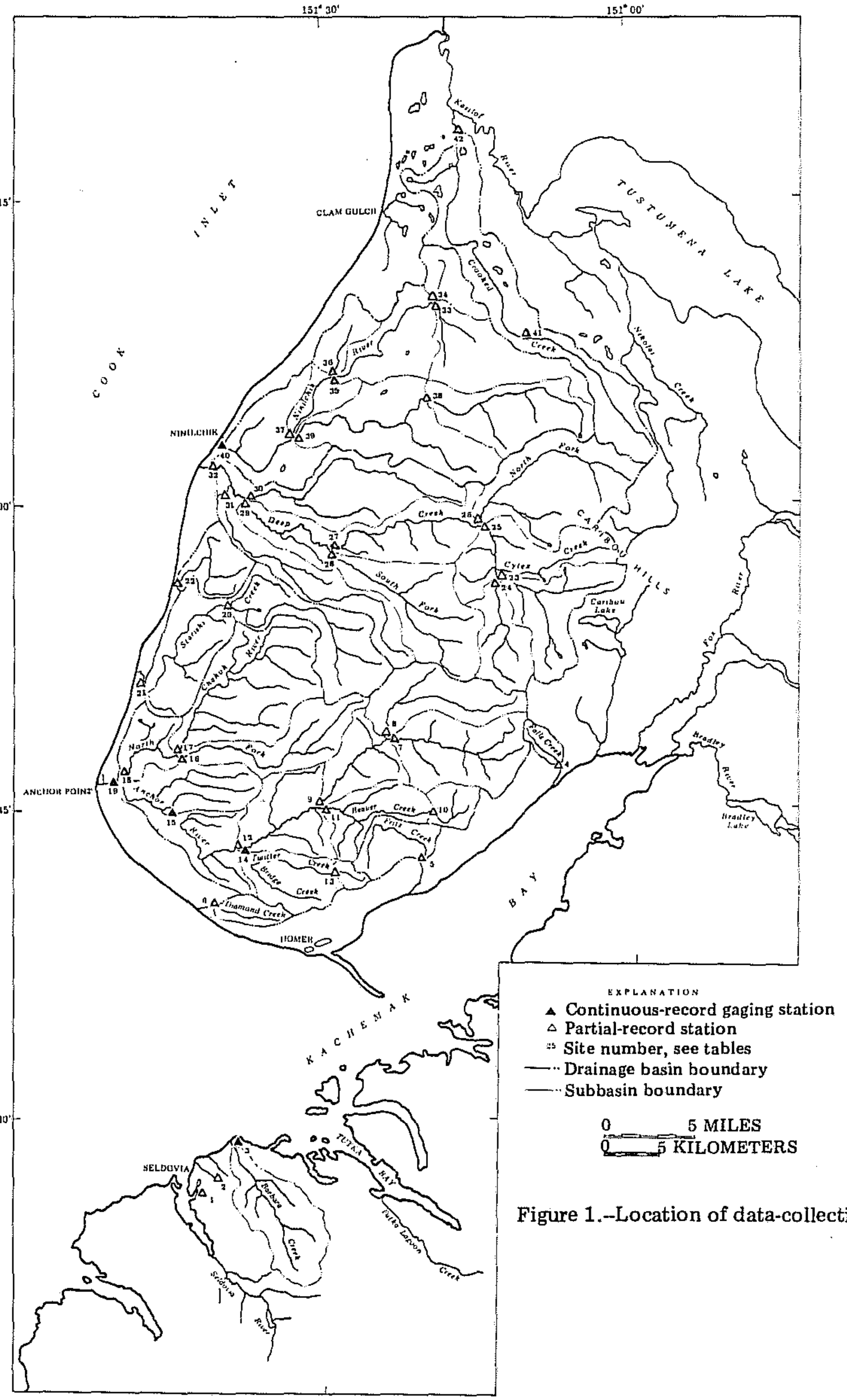

Figure 1.--Location of data-collection sites.

2,000 and 3,000 ft. The drainage is well defined. There are no lakes of signigicant size in the study area. Basins near Seldovia drain from the Kenai Mountains into Kachemak and Seldovia Bays.

The study area north of Homer has sedimentary bedrock of the Tertiary Kenai Group. Glacial deposits cover the bedrock and range from nothing to moderate depths (Karlstrom, 1964). The Seldovia area is underlain by igneous and metamorphic rocks of the Kenai Mountains. The climate of the area is transitional between the relatively mild maritime climate of the Gulf of Alaska and the dry, cold, continental climate of interior Alaska. The area is in the rain shadow of the Kenai Mountains. Mean annual precipitation ranges from 23.78 in. at Homer (records from 1937-79) to 16.60 in. at Kasilof (1946-79).

DATA COLLECTION

Streamflow was measured at 39 partial-record stations (sites 1-2, 4-14, 16-39, and 41-42, fig. 1). Station sites were selected in order to divide the large basins into subbasins of approximately equal area and to use sites for which earlier data were available (table 1). The discharge data can be found in the annual Water-Data Reports of the U.S. Geological Survey. Twelve discharge measurements were made at each partial-record station from September 1978 to August 1979. Additional discharge measurements were made during baseflow conditions between July 1978 and September 1980.

During the study period daily discharge data also were obtained at three long-term gaging stations: Barbara Creek near Seldovia, Anchor River near Anchor Point, and Ninilchik River at Ninilchik (sites 3, 15, and 40 respectively, fig. 1). Table 1 lists the gaging stations with their period of record. Two discontinued gaging stations, Twitter Creek near Homer and Anchor River at Anchor Point (sites 14 and 19 respectively), were measured as partial-record stations during the period July 1978 to September 1980.

STREAMFLOW CHARACTERISTICS AT GAGING STATIONS

To use the estimating techniques for the partial-record stations, suitable index gaging stations must be located nearby. Streamflow characteristics of an index gaging station can then be used to estimate the same characteristics for the partial-record station using the assumption that runoff from both watersheds will be similiar.

The annual mean discharge for the three index gaging stations ranged from 108 to 208 ft^3/s (table 2). During the 12-month period, September 1978 to August 1979, when the partial-record stations were measured intensively, the mean discharge ranged from 101 to 189 ft^3/s. Although the two means are very similiar for each station, timing of the runoff during the 12-month period was not normal. "Warm" storms occurred early in the winter, bringing rain instead of snow at low elevations,

TABLE 1. Summary of surface-water gaging stations and partial record stations.

[M-miscellaneous measurements; G-gaging station; L-low-flow partial-record station; P-crest-stage partial-record station]

Site no.	Station no.	Stream	Drainage area, square miles	Period of record, Water year	Average flow: Cubic feet per second	Average flow: Runoff, inches per year	Maximum observed discharge: Date	Maximum observed discharge: Discharge, Cubic feet per second	Maximum observed discharge: Discharge, Cubic feet per second per square mile	Minimum observed discharge: Date	Minimum observed discharge: Discharge, Cubic feet per second	Minimum observed discharge: Discharge, Cubic feet per second per square mile
		SELDOVIA DRAINAGE										
1	15238800	Fish Creek at Seldovia	3.83	M 1967, 1968, 1970, 1972, 1973 L July 1978-Sept. 1980						Mar. 8, 1973	0.98	0.26
2	15238810	Seldovia Lagoon tributary near Seldovia	0.93	M 1967, 1968, 1970, 1972 L July 1978-Sept. 1980						Aug. 18, 1978	0.06	0.06
3	15238820	Barbara Creek near Seldovia	20.7	G June 1972-Sept. 1981	109	71.5	Oct. 23, 1980	1,310	63.3	Feb.27-Apr.3, 1973 Mar. 18-Apr. 15, 1975	16	0.77
		NORTH SIDE KACHEMAK BAY DRAINAGE										
4	15239300	Falls Creek near Homer	2.84	L July 1978-Sept. 1980						Mar. 16, 1979	0.59	0.21
5	15239500	Fritz Creek near Homer	10.4	M 1962 P,M May 1963-Sept. 1981 L July 1978-Sept. 1980			Oct. 22, 1980	852	81.9	Jan. 13, 1969	0.85	0.08
6	15239800	Diamond Creek near Homer	5.35	M 1962 P,M Mar. 1963-Sept. 1981 L July 1978-Sept. 1980			Oct.22, 1980	255	47.7	Apr. 1, 1972	0.56	0.10
		ANCHOR RIVER DRAINAGE										
7	15239805	Anchor River near Homer	28.8	L July 1978-Sept. 1980						Mar. 14, 1979	14	0.49
8	15239807	Anchor River tributary at mouth near Homer	20.1	L July 1978-Sept. 1980						July 14, 1978	19	0.95
9	15239810	Anchor River above Beaver Creek near Homer	63.2	L July 1978-Sept. 1980						Nov. 8, 1978 Mar. 14, 1979	48	0.76
10	15239818	Beaver Creek near Bald Mountain near Homer	5.41	L July 1978-Sept. 1980						Mar. 16, 1979	1.0	0.18
11	15239822	Beaver Creek at mouth near Homer	19.8	L July 1978-Sept. 1980						Mar. 14, 1979	7.9	0.40
12	15239840	Anchor River above Twitter Creek near Homer	105	L July 1978-Sept. 1980						Aug. 16, 1978	63	0.60
13	15239845	Twitter Creek near Lookout Mountain near Homer	1.63	L July 1978-Sept. 1980						Mar. 19, 1979	0.49	0.30
14	15239880	Twitter Creek near Homer	16.1	G Aug. 1971-Sept. 1973 L July 1978-Sept. 1980			May 15, 1973	536	33.3	Apr. 4-6, 1973	3.9	0.24
15	15239900	Anchor River near Anchor Point	137	P 1974 G June 1965-Sept. 1973 G Sept. 1978-Sept. 1981	208	20.6	Oct. 23, 1980	4,680	34.2	Jan. 1-3, 1969	28	0.20
16	15239970	North Fork Anchor River above Chakok River near Anchor Point	18.4	L July 1978-Sept. 1980						Mar. 20, 1979	10	0.54
17	15239980	Chakok River near Anchor Point	38.7	L July 1978-Sept. 1980						Aug. 16, 1978 Mar. 20, 1979	14	0.36
18	15239990	North Fork Anchor River at mouth at Anchor Point	65.7	M 1951, 1952 L July 1978-Sept. 1980						Mar. 5, 1952	19	0.29
19	15240000	Anchor River at Anchor Point	224	M 1949, 1951 G June 1953-Sept. 1966 L July 1978-Sept. 1980	299	18.0	Mar. 8, 1963	3,030	13.5	July 28, 1953	28	0.12
		STARISKI CREEK DRAINAGE										
20	15240200	Stariski Creek near Ninilchik	27.0	L July 1978-Sept. 1980						Nov. 8, 1978	7.1	0.26
21	15240300	Stariski Creek near Anchor Point	49.4	M 1951, 1952, 1977 L July 1978-Sept. 1980						Mar. 5, 1952	14	0.28
		HAPPY CREEK DRAINAGE										
22	15240400	Happy Creek at Happy Valley	7.74	L July 1978-Sept. 1980						Aug. 15, 1978	3.8	0.49
		DEEP CREEK DRAINAGE										
23	15240600	Deep Creek above tributary No. 1 near Ninilchik	18.9	L July 1978-Sept. 1980						Aug. 17, 1978	7.5	0.40
24	15240700	Deep Creek tributary No. 1 at mouth near Ninilchik	16.0	L July 1978-Sept. 1980						Aug. 17, 1978	6.5	0.41
25	15240800	Deep Creek above North Fork near Ninilchik	58.5	L July 1978-Sept. 1980						Nov. 8, 1978	27	0.46
26	15240900	North Fork Deep Creek at mouth near Ninilchik	38.9	L July 1978-Sept. 1980						Nov. 8, 1978	26	0.67
27	15241000	Deep Creek above South Fork near Ninilchik	119	L July 1978-Sept. 1980						Nov. 8, 1978	37	0.31
28	15241100	South Fork Deep Creek at mouth near Ninilchik	29.4	L July 1978-Sept. 1980						Nov. 8, 1978	9.9	0.34
29	15241200	Deep Creek above tributary No. 2 near Ninilchik	161	L July 1978-Sept. 1980						Mar. 13, 1979	99	0.61
30	15241300	Deep Creek tributary No. 2 at mouth near Ninilchik	35.6	L July 1978-Sept. 1980						Mar. 13, 1979	10	0.28
31	15241400	Clam Creek near Ninilchik	20.0	L July 1978-Sept. 1980						Aug. 15, 1978	7.2	0.36
32	15241500	Deep Creek near Ninilchik	220	M 1951, 1952, 1954, 1959-1961, 1965-1968 L July 1978-Sept. 1980						Mar. 14, 1968	43	0.20
		NINILCHIK RIVER DRAINAGE										
33	15241510	Ninilchik River above tributary No. 1 near Clam Gulch	19.5	L July 1978-Sept. 1980						Nov. 8, 1978	5.7	0.29
34	15241520	Ninilchik River tributary No. 1 at mouth near Clam Gulch	7.58	L July 1978-Sept. 1980						Mar. 13, 1979	1.9	0.25
35	15241530	Ninilchik River above tributary No. 2 near Ninilchik	46.2	L July 1978-Sept. 1980						Nov. 8, 1978	17	0.37
36	15241540	Ninilchik River tributary No. 2 at mouth near Ninilchik	6.08	L July 1978-Sept. 1980						July 10, 1978	2.4	0.39
37	15241550	Ninilchik River above tributary No. 3 near Ninilchik	59.2	L July 1978-Sept. 1980						Nov. 8, 1978	14	0.24
38	15241570	Ninilchik River tributary No. 3 near Ninilchik	22.7	L July 1978-Sept. 1980						Mar. 13, 1979	2.1	0.09
39	15241590	Ninilchik River tributary No. 3 at mouth near Ninilchik	56.8	L July 1978-Sept. 1980						Nov. 8, 1978	9.0	0.16
40	15241600	Ninilchik River at Ninilchik	131	M 1951, 1952 G Apr. 1963-Sept. 1981	108	11.2	Apr. 24, 1974	1,240	9.5	July 20, 1966	30	0.23
		CROOKED CREEK DRAINAGE										
41	15242080	Crooked Creek near Clam Gulch	21.9	L July 1978-Sept. 1980						Nov. 8, 1978	7.2	0.33
42	15242100	Crooked Creek near Kasilof	53.8	M 1951, 1952, 1973-1975 L July 1978-Sept. 1980						Feb. 21, 1974	18	0.33

TABLE 2.-- Comparison of monthly and mean annual discharge of index gaging stations in the study area for the period of record and September 1978 to August 1979.

Site Number (Fig. 1)	Station name	Period of record	Monthly and mean annual discharge, in cubic feet per second												
			Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Annual
3	Barbara Creek near Seldovia	June 1972-Sept. 1981	159	100	55.1	62.0	46.6	33.3	38.7	174	274	167	85.5	92.2	109
		Sept.1978-Aug. 1979	215	89.9	83.1	45.0	29.6	21.6	43.5	155	244	132	111	66.2	104
15	Anchor River near Anchor Point	July 1965-Sept. 1973, Sept. 1978-Sept. 1981	269	198	106	82.1	78.4	95.5	210	640	314	153	152	189	208
		Sept.1978-Aug. 1979	244	183	216	105	72.5	85.2	326	567	146	116	90.4	107	189
40	Ninilchik River at Ninilchik	May 1963-Sept. 1981	130	102	63.2	55.7	57.8	66.3	163	235	121	89.3	88.7	116	108
		Sept.1978-Aug. 1979	109	79.9	85.9	68.4	58.6	72.2	252	195	77.8	74.4	63.3	77.7	101

resulting in higher than normal winter runoff. Also, higher than normal temperatures and below normal rainfall resulted in low summer runoff. The mean discharge for the period, September 1978 to August 1979, for all three index gaging stations, is within the standard deviation for annual mean discharges for the station.

Minimum flow during the year from streams in the study area may occur either during the the winter months or in July or August of a dry summer. At the time of minimum discharge, water released from storage in the ground or in lakes, ponds, and bogs provides all runoff for a basin. Instantaneous minimum flows are also caused by sudden drops in temperature from above freezing to below. Water goes into ice and channel storage. The effects of these freezing events do not last long and streamflow returns to normal basin yield in a short period. Low-flow frequency tables show how often the average discharge for prestated numbers of days may be expected to equal or be lower than a specified discharge. The graphical technique developed by Riggs (1972) was used to determine low-flow frequencies for the three index gaging stations (table 3). The 7-day 2-year low flows ranged from 0.35 to 0.87 $(ft^3/s)/mi^2$. The 7-day 10-year low flows ranged from 0.21 to 0.77 $(ft^3/s)/mi^2$.

ESTIMATES OF ANNUAL MEAN DISCHARGE FOR PARTIAL-RECORD STATIONS

Discharge data were collected over a wide range in stage at representative times throughout the year. Riggs's (1969) method was modified. Instead of using 12 measurements spaced equally throughout the year, more measurements were made during the spring snowmelt period, and fewer measurements were made during the winter baseflow period. These periods of time are listed in table 4. The mean discharge at each partial-record station for each period of time was then computed using an equation developed by Riggs:

$$Q = Q_a(Q_p/Q_i) \qquad (1)$$

where Q is average discharge for the period at the partial-record station;
Q_a is average discharge for the period at the index station;
Q_p is instantaneous discharge measured at the partial-record station;
Q_i is mean daily discharge recorded at the index station on the day discharge was measured at the partial-record station.

Discharge data for the partial-record stations were correlated with concurrent mean daily discharges at the gaging stations. The gaging station that correlated best was used as the index station for the partial-record station. Barbara Creek near Seldovia was used as the index station for 2 partial-record stations, Anchor River near Anchor Point for 28 partial-record stations, and Ninilchik River at Ninilchik for 9 partial-record stations.

TABLE 3.-- Seven-day low-flow frequencies for index gaging stations through 1983, using graphical analysis.

Site Number (Fig. 1)	Station name	Years of record	Mean discharge for seven consecutive days: in cubic feet per second, Recurrence interval in years: 2	10	in cubic feet per second per square mile, Recurrence interval in years: 2	10
3	Barbara Creek near Seldovia	9	18	16	0.87	0.77
15	Anchor River near Anchor Point	11	55	29	.40	.21
40	Ninilchik River at Ninilchik	18	46	36	.35	.27

TABLE 4.--Computation of mean discharge for Clam Creek near Ninilchik

[Data in cubic feet per second; $Q = Q_a \frac{Q_p}{Q_i}$]

Measurement date	Concurrent discharges: Clam Creek near Ninilchik (Q_p)	Concurrent discharges: Anchor River near Anchor Point (Q_i)	Period	Mean discharge: Anchor River near Anchor Point (Q_a)	Mean discharge: Clam Creek near Ninilchik (Q)	Seasonal mean discharge, Clam Creek near Ninilchik
Fall			1978			
9-13-78	22	211	September	107	11	17
10-09-78	25	266	October	244	23	
11-07-78	14	159	November	183	16	
Winter			1978-79			
1-03-79	12	125	December - January	160	15	11
3-20-79	8.2	90	February - March	79.2	7.2	
Snowmelt			1979			
4-16-79	28	180	April 1-25	243	38	42
4-30-79	70	761	April 26 - May 9	826	76	
5-14-79	47	577	May 10-23	518	42	
5-29-79	18	250	May 24 - June 7	252	18	
Summer			1979			
6-13-79	11	118	June 8-30	135	13	13
7-18-79	15	113	July	116	15	
8-14-79	14	113	August	90.4	11	
			Mean discharge, September 1978 to August 1979			19

A sample tabulation for Clam Creek near Ninilchik is shown on table 4. Seasonal mean discharges are the average of the mean discharges for the time periods within each season.

The annual mean discharge estimates for the 39 partial-record stations (table 5) ranged from 2.2 to 297 ft^3/s. The estimated annual mean discharges for the two discontinued gaging stations, Twitter Creek near Homer and Anchor River at Anchor Point, agreed within 6 and 0.7 percent, respectively, of the actual annual mean discharges computed from previous gaging station record.

To verify the method used above to estimate mean discharge on the basis of periodic discharge measurements, the seasonal and annual discharge for one of the index stations was computed by treating it as a partial-record station. Ninilchik River at Ninilchik was assumed to be the partial-record station and Anchor River near Anchor Point was used as its index station. The periodic discharge measurements made at Ninilchik River at Ninilchik were correlated with the mean daily discharge at Anchor River near Anchor Point. The mean discharge during the study year at Ninilchik River at Ninilchik was estimated to be 107 ft^3/s, which is 6 percent greater than the 101 ft^3/s computed from daily records. The deviation of the estimated mean discharge from the computed mean discharge is -7, +16, +8, and 0 percent for the fall, winter, snowmelt, and summer season, respectively.

ESTIMATES OF 7-DAY 10-YEAR LOW-FLOW DISCHARGE AT PARTIAL-RECORD STATIONS

Baseflow discharge data for the entire period of record for each partial-record station were used to estimate the 7-day 10-year low-flow discharge. Riggs (1972) used a graphical method to estimate the low-flow discharge for partial-record stations. An ordinary least squares regression model (Haan, 1977) was computed using the baseflow discharges of a partial-record station and concurrent mean daily discharges of an index gaging station in this study. The estimated 7-day 10-year low-flow discharge was computed from the index gaging station 7-day 10-year low-flow discharge and the regression model.

The regression model used the logarithm of the discharge. A correlation coefficient (r), a measure of the agreement or correlation between predicted and observed values, was computed for each regression. The standard error of the estimate was also computed; this is the value or magnitude, in appropriate units, of one standard deviation from the value estimated by the regression equation.

Discharge data collected during non-baseflow conditions were not used in the regression models. Thus measurements during peak and medium flows were excluded as were measurements made during periods of rapidly dropping, near freezing temperatures when ice and channel storage affected basin yield. Periods of storage generally last less than 1 day; therefore measurements during such periods should not be used in cor-

TABLE 5.--Estimates of mean discharge for partial-record stations based on 12 discharge measurements in 1978 and 1979

Site No. (Fig. 1)	Partial-record station	Mean discharge in cubic feet per second: Fall	Winter	Snowmelt	Summer	September 1978 to August 1979 a
1	Fish Creek at Seldovia	15	7.4	16	6.3	11
2	Seldovia Lagoon tributary near Seldovia	3.7	2.2	5.8	1.0	2.9
4	Falls Creek near Homer	3.0	1.1	6.9	1.6	2.7
5	Fritz Creek near Homer	11	6.8	24	5.0	11
6	Diamond Creek near Homer	5.7	3.3	14	2.2	5.7
7	Anchor River near Homer	33	17	79	19	33
8	Anchor River tributary at mouth near Homer	33	28	56	21	33
9	Anchor River above Beaver Creek near Homer	79	67	181	54	88
10	Beaver Creek near Bald Mountain near Homer	7.4	1.8	21	2.3	6.9
11	Beaver Creek at mouth near Homer	25	12	67	11	25
12	Anchor River above Twitter Creek near Homer	150	94	305	86	145
13	Twitter Creek near Lookout Mountain near Homer	1.7	1.0	6.4	1.2	2.2
14	Twitter Creek near Homer	18	10	55	9.7	20b
16	North Fork Anchor River above Chakok River near Anchor Point	31	14	51	16	253
17	Chakok River near Anchor Point	42	18	79	24	36
18	North Fork Anchor River at mouth at Anchor Point	79	33	172	48	74
19	Anchor River at Anchor Point	295	168	697	163	297c
20	Stariski Creek near Ninilchik	30	18	49	17	26
21	Stariski Creek near Anchor Point	44	31	109	28	48
22	Happy Creek at Happy Valley	11	5.7	24	5.7	10
23	Deep Creek above tributary 1 near Ninilchik	22	11	53	13	22
24	Deep Creek tributary 1 at mouth near Ninilchik	19	12	52	9.2	20
25	Deep Creek above North Fork near Ninilchik	62	36	145	46	65
26	North Fork Deep Creek at mouth near Ninilchik	47	41	87	42	51
27	Deep Creek above South Fork near Ninilchik	149	111	293	115	155
28	South Fork Deep Creek at mouth near Ninilchik	21	18	52	19	26
29	Deep Creek above tributary 2 near Ninilchik	198	121	416	134	198
30	Deep Creek tributary 2 at mouth near Ninilchik	20	14	52	16	23
31	Clam Creek near Ninilchik	17	11	42	13	19
32	Deep Creek near Ninilchik	252	157	571	190	265
33	Ninilchik River above tributary 1 near Clam Gulch	12	9.5	19	10	12
34	Ninilchik River tributary 1 at mouth near Clam Gulch	4.5	2.5	8.8	2.6	4.2
35	Ninilchik River above tributary 2 near Ninilchik	34	24	63	30	35
36	Ninilchik River tributary 2 at mouth near Ninilchik	5.7	2.8	11	3.3	5.2
37	Ninilchik River above tributary 3 near Ninilchik	39	23	79	37	41
38	Ninilchik River tributary 3 near Ninilchik	8.5	4.8	18	6.3	8.6
39	Ninilchik River tributary 3 at mouth near Ninilchik	39	27	73	26	39
41	Crooked Creek near Clam Gulch	29	25	29	21	26
42	Crooked Creek near Kasilof	57	32	104	40	54

a Mean for September 1978 to August 1979 is considered representative of long-term mean discharge.
b Mean for period of gaging station operation (1972-73 water years) is 21.2 ft^3/s.
c Mean for period of gaging station operation (1954-66 water years) is 299 ft^3/s.

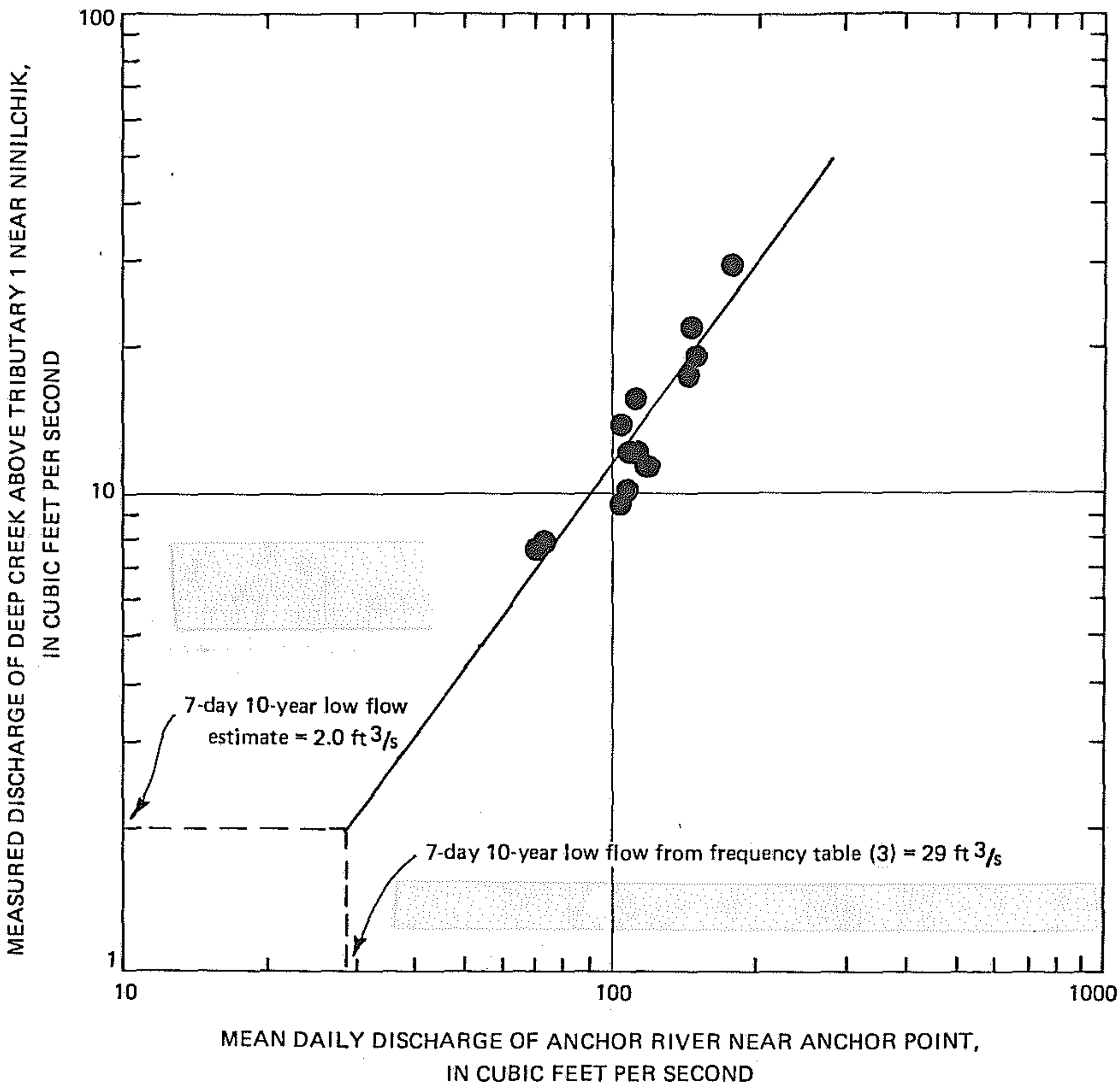

Figure 2.--Relation of base-flow measurements at a low-flow partial-record station (Deep Creek above tributary 1 near Ninilchik) to concurrent mean daily discharge at a gaging station (Anchor River near Anchor Point) for the period 1978-80.

TABLE 6.-- Regression coefficients and low-flow discharge values for partial-record stations.

$\log 10(\text{P-R STATION}) = a + b * \log 10(\text{INDEX GAGE})$

Site Number	Station name	Slope b	Intercept a	R	Syx	Estimated 7-day 10-year low-flow discharge (ft³/s)	
						(ft^3/s)	$[(ft^3/s)/mi^2]$
1	Fish Creek at Seldovia	.83	-0.86	.69	.31	1.4	.36
2	Seldovia Lagoon tributary near Seldovia	.97	-1.94	.52	.51	.17	.18
4	Falls Creek near Homer	1.43	-2.74	.86	.11	.22	.08
5	Fritz Creek near Homer	1.23	-1.75	.94	.08	1.1	.11
6	Diamond Creek near Homer	1.34	-2.30	.86	.13	.45	.08
7	Anchor River near Homer	.79	-0.32	.75	.08	6.7	.23
8	Anchor River tributary at mouth near Homer	.38	.59	.71	.04	14	.68
9	Anchor River above Beaver Creek near Homer	.58	.57	.85	.04	26	.42
10	Beaver Creek near Bald Mountain near Homer	2.00	-3.73	.87	.15	.15	.03
11	Beaver Creek at mouth near Homer	1.09	-1.14	.87	.08	2.9	.15
12	Anchor River above Twitter Creek near Homer	.78	.36	.95	.03	31	.30
13	Twitter Creek near Lookout Mountain near Homer	1.08	-2.11	.62	.16	.29	.18
14	Twitter Creek near Homer	1.24	-1.47	.89	.10	2.2	.13
16	North Fork Anchor River above Chakok River near Anchor Point	.77	-0.42	.79	.07	5.2	.28
17	Chakok River near Anchor Point	1.09	-0.89	.82	.08	5.0	.13
18	North Fork Anchor River at mouth at Anchor Point	1.16	-0.72	.81	.09	9.4	.14
19	Anchor River at Anchor Point	1.09	-0.01	.97	.03	39	.17
20	Stariski Creek near Ninilchik	.39	.46	.57	.07	10	.38
21	Stariski Creek near Anchor Point	.93	-0.41	.89	.06	8.9	.18
22	Happy Creek at Happy Valley	.92	-1.11	.76	.10	1.7	.22
23	Deep Creek above tributary 1 near Ninilchik	1.38	-1.72	.91	.09	2.0	.10
24	Deep Creek tributary 1 at mouth near Ninilchik	1.04	-1.11	.79	.10	2.5	.16
25	Deep Creek above North Fork near Ninilchik	.94	-0.29	.83	.08	12	.21
26	North Fork Deep Creek at mouth near Ninilchik	.29	1.00	.54	.06	27	.69
27	Deep Creek above South Fork near Ninilchik	.50	1.02	.73	.06	58	.48
28	South Fork Deep Creek at mouth near Ninilchik	.48	.29	.70	.06	9.7	.33
29	Deep Creek above tributary 2 near Ninilchik	.67	.77	.75	.07	55	.34
30	Deep Creek tributary 2 at mouth near Ninilchik	.47	.21	.62	.08	8.1	.23
31	Clam Creek near Ninilchik	.88	-0.74	.84	.06	3.6	.18
32	Deep Creek near Ninilchik	.86	.44	.80	.10	52	.24
33	Ninilchik River above tributary 1 near Clam Gulch	.92	-0.72	.62	.08	5.2	.26
34	Ninilchik River tributary 1 at mouth near Clam Gulch	1.51	-2.32	.73	.10	1.1	.15
35	Ninilchik River above tributary 2 near Ninilchik	1.16	-0.71	.73	.07	12	.26
36	Ninilchik River tributary 2 at mouth near Ninilchik	1.06	-1.43	.55	.11	1.7	.28
37	Ninilchik River above tributary 3 near Ninilchik	1.06	-0.43	.63	.09	16	.27
38	Ninilchik River tributary 3 near Ninilchik	.91	-1.11	.68	.12	1.6	.07
39	Ninilchik River tributary 3 at mouth near Ninilchik	.59	.33	.66	.05	18	.32
41	Crooked Creek near Clam Gulch	.54	.33	.74	.03	15	.68
42	Crooked Creek near Kasilof	.88	.00	.67	.12	23	.43

relations for estimating average discharges for periods of 7 days or longer. These measurements should be used if an analysis is done for the 1 and 3-day low-flow discharge.

An example regression model for Deep Creek above tributary 1 is shown in figure 2. The estimated 7-day 10-year low-flow discharge is computed to be 2.0 ft^3/s, using Anchor River near Anchor Point as the index gaging station.

The estimated 7-day 10-year low-flow discharges for the 39 partial-record stations (table 6) ranged from 0.15 to 58 ft^3/s. Discharges per square mile ranged from 0.03 to 0.69 $(ft^3/s)/mi^2$. The correlation coefficients ranged from 0.52 to 0.97, and were greater than 0.65 for 33 of the correlations indicating 'fair to good' correlations between the discharges of the two stations. The standard error of the estimates ranged from 0.03 to 0.51 log units. Most stations ranged from 0.03 to 0.12 indicating fairly small errors between the predicted and observed discharges.

SUMMARY

Twelve discharge measurements made during the period September 1978 to August 1979 were used to estimate annual mean discharge at 39 partial-record stations in the lower Kenai Peninsula. The estimates were made using the ratios of the instantaneous discharge at the partial-record station to the concurrent mean daily discharge at the index station and the periodic mean discharges of the partial-record station to the index gaging station as being equal. Estimates of the annual mean flow ranged from 2.2 to 297 ft^3/s for the partial-record stations.

An ordinary least squares linear regression model was computed for each of the 39 partial-record stations using baseflow discharges at the partial-record station and concurrent mean daily discharges at an index gaging station. The 7-day 10-year low-flow discharge was estimated for each partial-record station using the regression model and the 7-day 10-year low-flow discharge of the index gaging station. Estimates of the 7-day 10-year low-flow discharge ranged from 0.03 to 0.69 $(ft^3/s)/mi^2$ for the partial-record stations.

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ESTIMATING PEAK FLOWS FROM CHANNEL WIDTHS IN ALASKA

by Bruce Parks[1] and Robert D. Lamke[2]

ABSTRACT

Several investigators have related channel geometry to peak flow characteristics, on the premise that the measurable physical dimensions of a channel are caused by flood flows. Bankfull channel width, a characteristic commonly used in these studies, is here shown to be applicable for estimating peak flows in Alaskan streams.

Channel widths used in this study are taken from discharge measurements made at U.S. Geological Survey gaging stations where floodflow frequencies have also been determined. In lieu of field measurements, the widths used are those which would occur during a two-year peak, a flow that corresponds to bankfull stage.

Equations developed for this report relate the 2-, 5-, 10-, 25-, 50-, and 100-year peak flows to channel widths; these equations can be used to estimate flood characteristics at ungaged sites from width measurements. Equations for two distinct climatic regions are also presented and show that the standard errors for this method are similar in magnitude to the standard errors of previously published equations which used basin characteristics to estimate these same peak flows.

INTRODUCTION

The most commonly used technique for estimating flood frequency statistics at ungaged sites in Alaska is to develop and apply equations based on the physical and climatic characteristics of a drainage basin (Lamke, 1979). This report examines an alternative method for estimating flood-flow magnitudes and frequencies at ungaged sites.

A number of investigators have shown that prominent physical dimensions of a channel are a function (or result) of the peak discharges found in the stream (Wahl, 1977; Riggs, 1978). Both width and depth were evaluated as variables in these studies. Depth was not used in our analysis because it is more difficult to determine adequately in the field (Wahl, 1977); width is the only variable used here.

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Field measurements of the widths were not obtained specifically for this study. Width dimensions used were determined from discharge and slope-area measurement notes for sites at which flood magnitude and frequency relations have been reasonably well defined. All stream-gaging and crest-stage partial-record stations in Alaska with 10 or more years of peak discharge data were evaluated; 117 sites had adequate data to define their bankfull width.

Statewide equations derived using linear regression techniques equate peak discharges for a series of recurrence intervals (2-, 5-, 10-, 25-, 50-, and 100-years) to the bankfull width of the stream. Similar equations were developed for the two areas of Alaska for which Lamke (1979) related flood characteristics to basin characteristics.

DATA USED IN ANALYSIS

To obtain reasonable estimates of bankfull widths at as many sites as possible, all streamflow gaging stations in Alaska for which at least 10 annual peaks have been defined were evaluated for inclusion in this report. Flood frequency characteristics were computed using a log-Pearson Type III distribution with adjustments for historical peaks, low outliers, zero flow years, and high outliers according to U.S. Water Resources Council Bulletin 17B (1981). Sites at which annual peaks have been affected by outbursts from glacier-dammed lakes were not used. Also, many sites with suitable flood records were not used because appropriate widths could not be determined. Sites were not used in this analysis if:

* Widths were not free to adjust to changes in discharge, within the range of discharges used, because of man-made constraints such as bridge abutments or channelized flow;

* The range of discharge measurements was not great enough to determine the channel width for a 2-year peak;

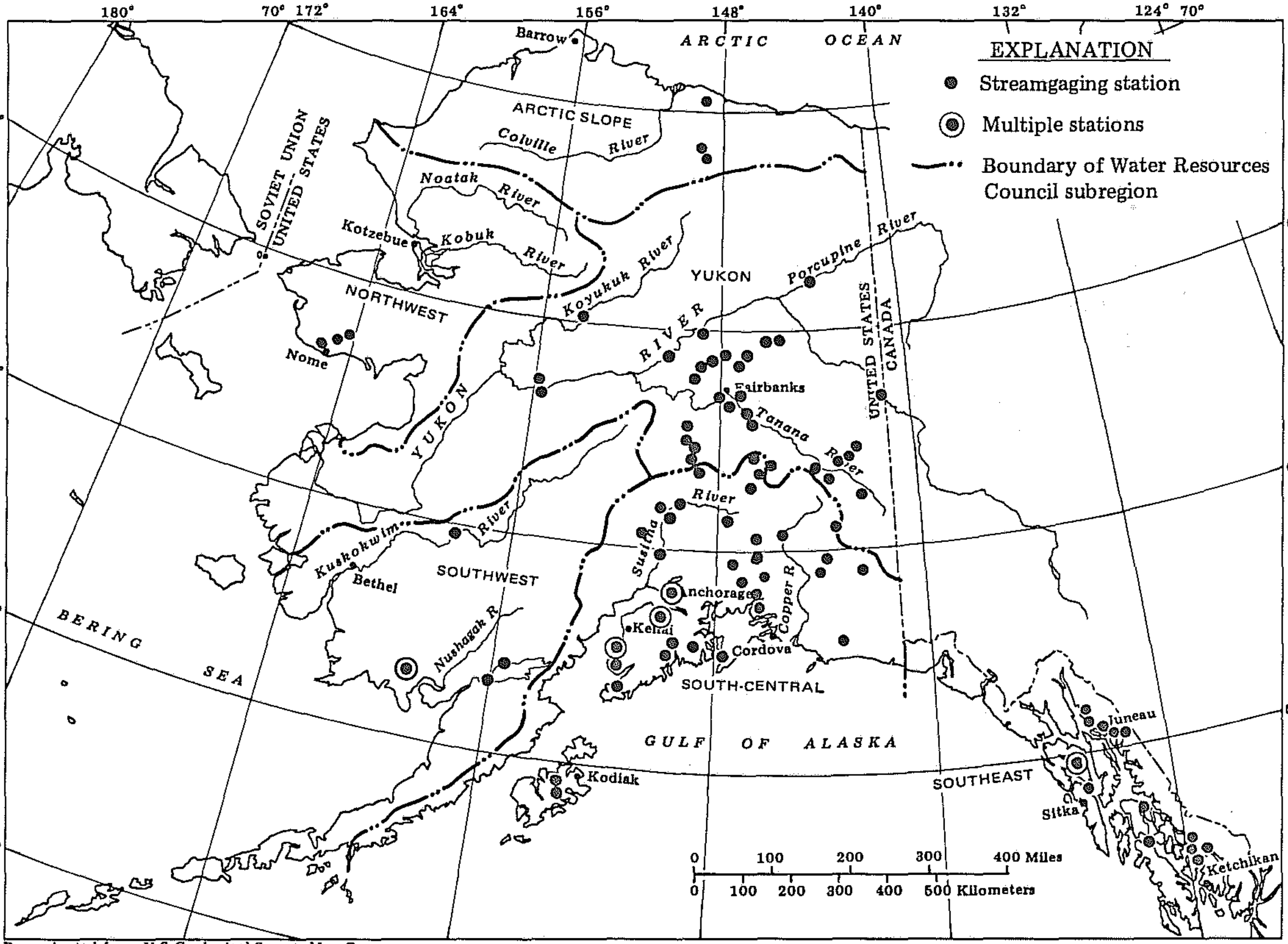
* The channel characteristics of sites used for wading measurements differed from those of the sites used for discharge measurements of larger discharges; and

* A log-transformed linear regression of widths versus discharge at the site gave a coefficient of determination of less than 0.50.

The 117 stations included in this analysis are listed in table 1 and their areal distribution is shown in figure 1.

METHOD USED TO DETERMINE WIDTHS

The widths used in this report are those that correspond to the 2-year peak, which is closely associated with bankfull stage. This concept is from Wolman and Leopold (1957), who showed that most rivers reach a stage at or above the surface of the flood plain every year or every



Base adapted from U.S.Geological Survey Map C

Figure 1. -- Location of streamgaging sites used in this analysis.

TABLE 1.--Gaging stations and corresponding physical and flood-frequency characteristics used in this analysis.

OBS. NO.	STATION NUMBER	STATION NAME	LOCATION LAT	LONG	WIDTH (ft)	DRAINAGE AREA (mi^2)	P_2 (ft^3/s)	P_5 (ft^3/s)	P_{10} (ft^3/s)	P_{25} (ft^3/s)	P_{50} (ft^3/s)	P_{100} (ft^3/s)
1	15012000	Winstanley C nr Ketchikan	55.42	130.87	53.3	15.5	1190	1730	2160	2780	3320	3910
2	15022000	Harding R nr Wrangell	56.21	131.64	175	67.4	6730	9110	10800	13000	14700	16400
3	15034000	Long R nr Juneau	58.17	133.70	96.3	32.5	3110	4170	4930	5970	6790	7670
4	15036000	Speel R nr Juneau	58.20	133.61	307	226	18200	24400	28700	34700	39500	44500
5	15040000	Dorothy C nr Juneau	58.23	134.04	50.0	15.2	848	1170	1410	1730	1990	2270
6	15050000	Gold C at Juneau	58.31	134.40	55.6	9.76	1310	1760	2080	2510	2850	3210
7	15054500	Bessie C nr Auke Bay	58.59	134.90	25.6	1.35	165	241	292	356	404	452
8	15056200	West C nr Skagway	59.53	135.35	141	43.2	2630	3820	4760	6140	7320	8630
9	15072000	Fish C nr Ketchikan	55.39	131.19	173	32.1	2890	3580	4030	4590	5000	5410
10	15076000	Manzanita C nr Ketchikan	55.60	130.98	91.5	33.9	2790	3550	4030	4620	5040	5450
11	15086600	Big C nr Point Baker	56.13	133.14	67.1	11.2	1020	1260	1410	1570	1680	1790
12	15087250	Twin C nr Petersburg	56.72	132.93	36.4	3.01	448	582	669	777	858	938
13	15098000	Baranof R at Baranof	57.09	134.84	132	32.0	2800	3790	4530	5600	6480	7440
14	15106920	Kadashan R ab Hook C nr Tenakee	57.66	135.19	76.4	10.2	1130	1460	1680	1960	2160	2350
15	15106940	Hook C ab Trib nr Tenakee	57.68	135.13	36.2	4.48	711	1080	1340	1680	1940	2200
16	15106960	Hook C nr Tenakee	57.67	135.18	45.5	8.00	1180	1480	1660	1860	2000	2130
17	15106980	Tonalite C nr Tenakee	57.68	135.22	73.4	14.5	2190	3070	3630	4300	4780	5250
18	15195000	Dick C nr Cordova	60.34	144.30	66.9	7.95	1960	2180	2320	2480	2590	2700
19	15198500	Station C nr Mentasta	62.94	143.67	25.9	15.3	151	294	422	626	813	1030
20	15201000	Dry C nr Glennallen	62.15	145.48	22.2	11.4	69.6	242	468	950	1500	2280
21	15201100	Little Nelchina R Tr nr Eureka Lodge	61.99	147.01	15.0	7.81	40.1	79.8	116	176	231	296
22	15201900	Moose C Trib at Glennallen	62.11	145.52	13.8	7.12	31.2	99.4	189	384	616	952
23	15206000	Klutina R at Copper Center	61.95	145.31	175	880	6890	7750	8270	8890	9330	9760
24	15208000	Tonsina R at Tonsina	61.66	145.18	172	420	4500	5960	6950	8230	9200	10200
25	15208100	Squirrel C at Tonsina	61.67	145.17	33.2	70.5	313	506	660	886	1080	1290
26	15208200	Rock C nr Tonsina	61.76	145.15	19.8	14.3	49.6	85.2	114	158	195	237
27	15209100	May C nr May Creek	61.35	142.70	14.4	10.4	50.6	92.6	130	190	245	310
28	15211700	Strelna C nr Chitina	61.51	144.07	25.0	23.8	186	278	346	440	516	597
29	15211900	O'Brien C nr Chitina	61.48	144.46	49.5	44.8	585	998	1370	1970	2530	3210
30	15212000	Copper R nr Chitina	61.47	144.46	744	20600	166000	203000	229000	265000	294000	324000
31	15212500	Boulder C nr Tiekel	61.34	145.31	30.6	9.80	213	363	501	734	958	1230
32	15216000	Power C nr Cordova	60.59	145.62	98.0	20.5	2780	3990	4790	5770	6490	7190
33	15219000	WF Olsen Bay C nr Cordova	60.76	146.17	35.0	4.78	562	750	872	1020	1140	1250
34	15219100	Control C nr Cordova	60.75	146.23	45.0	4.22	552	788	962	1200	1400	1610
35	15236900	Wolverine C nr Lawing	60.37	148.90	31.2	9.51	826	1160	1410	1730	2000	2270
36	15237400	Chalmers R nr Cordova	60.22	147.23	80.0	6.32	2710	3160	3410	3690	3870	4040
37	15238000	Lost C nr Seward	60.20	149.38	28.0	7.96	335	464	561	699	812	935
38	15238600	Spruce C nr Seward	60.07	149.45	57.2	9.26	1610	2410	2950	3640	4160	4680
39	15238820	Barbara C nr Seldovia	59.48	151.65	56.8	20.7	659	971	1200	1520	1770	2040

TABLE 1.--Gaging stations and corresponding physical and flood-frequency characteristics used in this analysis--Continued.

OBS. NO.	STATION NUMBER	STATION NAME	LOCATION LAT	LOCATION LONG	WIDTH (ft)	DRAINAGE AREA (mi^2)	P_2 (ft^3/s)	P_5 (ft^3/s)	P_{10} (ft^3/s)	P_{25} (ft^3/s)	P_{50} (ft^3/s)	P_{100} (ft^3/s)
40	15239000	Bradley R nr Homer	59.76	150.85	177	54.0	3120	4540	5550	6890	7950	9040
41	15239500	Fritz C nr Homer	59.71	151.34	23.5	10.4	108	244	383	628	873	1180
42	15240000	Anchor R at Anchor Point	59.77	151.83	93.8	226	1930	2390	2710	3120	3430	3760
43	15240500	Cook Inlet Trib nr Ninilchik	59.98	151.72	16.8	5.19	51.4	76.2	95.4	123	146	171
44	15241600	Ninilchik R at Ninilchik	60.05	151.66	60.4	131	726	989	1180	1450	1660	1890
45	15242000	Kasilof R nr Kasilof	60.32	151.26	200	738	8030	9830	11000	12400	13500	14600
46	15243950	Porcupine C nr Primrose	60.34	149.37	63.7	16.8	752	1250	1680	2400	3060	3850
47	15254000	Crescent C nr Cooper Landing	60.50	149.68	41.7	31.7	330	524	691	952	1190	1470
48	15258000	Kenai R at Cooper Landing	60.49	149.81	355	634	11200	14900	17500	21100	24000	27000
49	15260000	Cooper C nr Cooper Landing	60.43	149.82	47.3	31.8	298	418	511	648	763	891
50	15267900	Resurrection C nr Hope	60.89	149.64	52.5	149	1290	1990	2560	3420	4160	5010
51	15269500	Granite C nr Portage	60.73	149.28	55.0	28.2	991	1520	1910	2470	2920	3400
52	15272530	California C at Girdwood	60.96	149.13	25.9	6.96	213	371	506	714	900	1110
53	15273900	SF Campbell C at Canyon Mth nr Anchorage	61.15	149.72	25.7	25.2	233	327	394	484	555	630
54	15274000	SF Campbell C nr Anchorage	61.17	149.77	30.7	30.4	214	328	424	574	709	866
55	15274800	SB, SF Chester C nr Anchorage	61.21	149.73	9.0	10.8	24.4	38.5	49.2	64.3	76.7	90.0
56	15275000	Chester C at Anchorage	61.20	149.84	20.8	20.0	69.3	87.2	98.6	113	123	133
57	15275100	Chester C at Arctic Blvd at Anchorage	61.21	149.90	20.9	27.2	98.9	123	141	163	181	200
58	15276000	Ship C nr Anchorage	61.22	149.63	52.7	90.5	834	1100	1280	1530	1720	1920
59	15277100	Eagle R at Eagle River	61.31	149.56	126	192	3280	4140	4750	5580	6230	6920
60	15282000	Caribou C nr Sutton	61.80	147.68	122	289	4380	5990	7130	8650	9840	11100
61	15291200	Maclaren R nr Paxson	63.12	146.53	300	280	5470	6770	7660	8840	9750	10700
62	15292000	Susitna R at Gold Creek	62.77	149.69	446	6160	48000	64200	75600	90900	103000	115000
63	15292400	Chulitna R nr Talkeetna	62.56	150.23	336	2570	39500	48800	55400	64300	71400	78800
64	15292700	Talkeetna R nr Talkeetna	62.35	150.02	359	2006	29100	40500	49100	61200	71200	82000
65	15293000	Caswell C nr Caswell	61.95	150.05	22.7	19.6	95.7	146	183	233	272	314
66	15294025	Moose C nr Talkeetna	62.32	150.44	75.0	52.3	1160	1620	1960	2460	2860	3310
67	15297200	Myrtle C nr Kodiak	57.60	152.40	50.7	4.74	753	951	1080	1240	1360	1480
68	15297475	Red Cloud C Trib nr Kodiak	57.82	152.62	27.3	1.51	413	547	632	737	813	888
69	15300500	Kvichak R at Igiugig	59.33	155.90	512	6500	33600	41600	46900	53500	58500	63500
70	15302900	Moody C at Aleknagik	59.28	158.60	11.3	1.28	26.6	35.5	42.1	51.2	58.5	66.4
71	15303000	Wood R nr Aleknagik	59.28	158.59	303	1110	13500	18000	21300	25800	29500	33400
72	15303010	Silver Salmon C nr Aleknagik	59.23	158.67	28.8	4.46	107	164	210	279	337	403
73	15304000	Kuskokwim R at Crooked Creek	61.87	158.10	1340	31100	166000	231000	276000	338000	387000	438000
74	15305900	Dennison Fork nr Tetlin Jct	63.42	142.48	8.9	2.93	24.4	44.1	62.3	92.8	122	158
75	15305920	WF Trib nr Tetlin Jct	63.67	142.27	13.7	1.02	32.8	61.4	87.0	128	166	211
76	15305950	Taylor C nr Chicken	63.91	142.22	21.2	38.4	109	223	337	540	746	1010
77	15356000	Yukon R at Eagle	64.79	141.20	1540	113500	285000	361000	415000	489000	547000	608000
78	15367500	Bluff C nr Eagle	64.75	141.23	7.2	3.38	5.8	15.1	26.6	51.1	80.3	123

TABLE 1.--Gaging stations and corresponding physical and flood-frequency characteristics used in this analysis--Continued.

OBS. NO.	STATION NUMBER	STATION NAME	LOCATION LAT	LOCATION LONG	WIDTH (ft)	DRAINAGE AREA (mi^2)	P_2 (ft^3/s)	P_5 (ft^3/s)	P_{10} (ft^3/s)	P_{25} (ft^3/s)	P_{50} (ft^3/s)	P_{100} (ft^3/s)
79	15389000	Porcupine R nr Fort Yukon	66.99	143.14	1320	29500	156000	229000	282000	355000	414000	476000
80	15438500	Bedrock C nr Central	65.56	145.09	14.7	9.94	105	228	347	549	744	982
81	15439800	Boulder C nr Central	65.57	144.89	24.3	31.3	271	472	650	936	1200	1510
82	15457700	Erickson C nr Livengood	65.58	148.94	28.4	26.3	284	547	789	1190	1560	2010
83	15468000	Yukon R at Rampart	65.51	150.17	1970	199400	553000	736000	862000	1030000	1150000	1280000
84	15469900	Silver C nr Northway Jct	62.98	141.67	11.0	11.7	31.4	90.3	168	342	558	885
85	15470000	Chisana R nr Northway Jct	63.01	141.80	202	3280	7710	8880	9660	10700	11400	12200
86	15473950	Clearwater C nr Tok	63.17	143.20	37.8	36.4	294	616	923	1440	1940	2540
87	15476000	Tanana R nr Tanacross	63.39	143.75	276	8550	29900	33600	35800	38500	40500	42400
88	15476049	Tanana R Trib nr Cathedral Rapids	63.41	143.81	11.6	3.09	76.2	190	312	533	759	1050
89	15476300	Berry C nr Dot Lake	63.69	144.36	55.5	65.1	640	1080	1460	2070	2630	3290
90	15478010	Rock C nr Paxson	63.07	146.10	67.6	50.3	675	1160	1550	2110	2600	3130
91	15478040	Phelan C nr Paxson	63.24	145.47	54.5	12.2	945	1380	1730	2220	2640	3100
92	15478500	Ruby C nr Donnelly	63.63	145.88	29.0	5.32	123	271	412	646	866	1130
93	15480000	Banner C at Richardson	64.29	146.35	34.2	20.2	153	394	653	1130	1620	2240
94	15484000	Salcha R nr Salchaket	64.47	146.92	407	2170	16600	25600	32100	41000	48000	55300
95	15490000	Monument C at Chena Hot Springs	65.05	146.05	30.7	26.7	283	599	916	1480	2040	2740
96	15511000	Little Chena R nr Fairbanks	64.89	147.25	100	372	1780	3350	4930	7760	10700	14400
97	15514000	Chena R at Fairbanks	64.85	147.70	296	1980	9140	14700	19200	26000	31900	38600
98	15516000	Nenana R nr Windy	63.46	148.80	214	710	6520	8060	9080	10400	11400	12400
99	15516200	Slime C nr Cantwell	63.51	148.81	21.0	6.90	166	269	359	501	631	784
100	15518000	Nenana R nr Healy	63.85	148.94	294	1910	20900	27400	32100	38300	43300	48500
101	15518200	Rock C nr Ferry	64.03	149.14	34.5	8.17	200	570	1020	1960	3030	4530
102	15518250	Birch C nr Rex	64.18	149.29	24.9	4.10	79.3	185	295	493	695	951
103	15519200	Brooks C Trib nr Livengood	65.38	148.94	17.1	7.81	43.4	115	191	333	477	660
104	15520000	Idaho C nr Miller House	65.35	146.16	28.3	5.31	119	259	409	691	990	1390
105	15530000	Faith C nr Chena Hot Springs	65.29	146.38	85.2	61.1	1300	2160	2930	4200	5380	6810
106	15541600	Globe C nr Livengood	65.29	148.13	31.5	23.0	267	544	810	1260	1700	2240
107	15541650	Globe C Trib nr Livengood	65.28	148.12	30.5	9.01	133	242	342	510	671	868
108	15541800	Washington C nr Fox	65.15	147.86	33.5	46.7	599	1280	1980	3240	4510	6150
109	15564600	Melozitna R nr Ruby	64.79	155.56	301	2693	19600	27200	32600	39600	45100	50800
110	15564800	Yukon R at Ruby	64.74	155.49	2870	259000	587000	749000	854000	984000	1080000	1180000
111	15564900	Koyukuk R at Hughes	66.05	154.26	1260	18700	119000	168000	203000	251000	290000	332000
112	15625000	Arctic C nr Nome	64.64	165.71	17.5	1.76	58.7	109	155	231	302	388
113	15668100	Star C nr Nome	64.93	164.96	24.2	3.78	73.4	115	146	189	224	262
114	15668200	Crater C nr Nome	64.93	164.87	156	21.9	859	1410	1870	2570	3180	3880
115	15896000	Kuparuk R nr Deadhorse	70.28	148.96	1610	3130	47300	79800	107000	149000	186000	228000
116	15910000	Sagavanirktok R nr Sagwon	69.09	148.76	461	2208	19300	28000	34300	42800	49500	56500
117	15910200	Happy C at Happy Valley Camp nr Sagwon	69.15	148.83	46.3	34.5	682	1050	1340	1760	2110	2490

other year; and from Emmett (1972, p. 12), who found that for 10 sites along the Trans Alaska Pipeline System (TAPS) corridor, "the average value of bankfull frequency is about 1.5 years." Similarly, Hedman and Osterkamp (1982) report that "the bankfull level of many perennial-stream channels approximates the stage of a flood with a recurrence interval ranging from 1.5 to 3 years."

Childers et al. (1973; 1977; 1979), and Childers and Kernodle (1981; 1983) determined bankfull channel widths at several ungaged sites for areas in Alaska with sparse data. Bankfull width data are also available from a series of reports on channel erosion along the TAPS corridor (Childers, 1972; 1974; 1975; and Childers and Jones, 1975), but these studies did not address flood frequency distributions.

Bankfull stage used in this report is the stage at which the channel just begins to overflow the flood plain (Wolman, 1955, p. 29; Emmett, 1972, p. 4; and Hedman and Osterkamp, 1982, p. 4). Criteria for selecting a suitable reach of a stream are defined by Riggs (1978, p. 89): "(1) Channel shape should be uniform throughout; (2) the bed and banks should be of a material that has permitted the channel to develop into a normal size and shape for the flow regimen; and (3) channel banks should appear to have been permanent for some years." "The reference level for this section (bankfull stage) is variously defined by breaks in bank slope, by the edges of the flood plain, or by the lower limits of permanent vegetation." Figure 2 shows a typical stream cross section and its corresponding bankfull channel width.

In the absence of field measurements for this report, widths were determined from discharge and slope-area measurement notes. A sample of 5 to 12 cross sections was selected, representing discharges ranging from those close to the 2-year peak to those near the mean-annual flow. The selected cross sections were examined to delete any overbank widths and discharges (only a few stations needed this correction). A width corresponding to the 2-year peak was then computed using a log transformed linear regression of widths versus discharges for each site.

Examples of data for two representative stations are shown in table 2, and a graphical representation of the data is shown in figure 3. Values of the 2-year peak are given along with the corresponding width and the equation derived to compute that width.

COMPUTATIONS

The general form of the multiple linear-regression models which were used in this report is:

$$y = a + bx$$

where y is the floodflow characteristic (dependent variable);
a is the regression constant;
b is the regression coefficient; and
x is the width (independent variable).

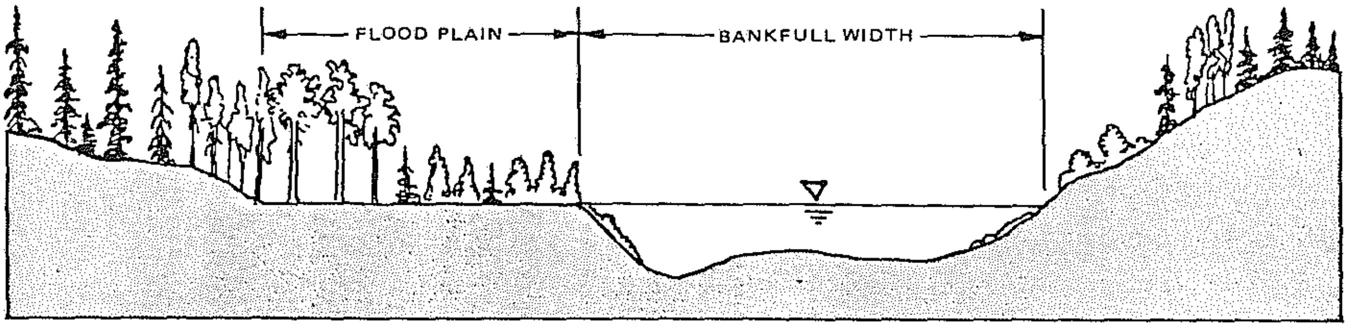


Figure 2. – Typical stream cross section and its bankfull channel width.

TABLE 2.--Example of data used to compute width at 2-year peak for two sites.

Measurement number	Date	Discharge (ft^3/s)	Width (ft)	Remarks
		15087250 Twin Creek near Petersburg		
18	08-15-70	48.8	30.5	Wading 500 ft upstream
21	10-17-70	51.1	30	Wading 20 ft upstream
22	01-07-71	146	31	Wading at gage
23	05-14-71	31.7	24.9	Wading at gage
24	10-16-71	75.9	33	Wading at gage
29	11-01-71	165	35.5	Wading downstream
--	11-03-76	a550	b35	Slope area-section 1
--	11-03-76	a550	b33	Slope area-section 2
--	11-03-76	a550	b42	Slope area-section 3
		15484000 Salcha River near Salchaket		
185	05-14-71	11200	364	Upstream side of bridge
193	05-11-72	10100	336	Upstream side of bridge
199	05-12-73	5380	275	Upstream side of bridge
200	06-28-73	3840	325	Upstream side of bridge
201	08-15-73	3090	280	Upstream side of bridge
215	05-14-75	19600	416	Downstream side of bridge
223	07-29-76	1700	276	Upstream side of bridge
233	05-02-78	1940	261	Downstream side of bridge
240	05-03-79	14200	428	Upstream side of bridge
254	06-29-81	8890	414	Downstream side of bridge
255	07-10-81	15300	409	Downstream side of bridge
259	07-09-82	1270	250	Downstream side of bridge

a Annual maximum discharge.
b Surveyed cross-sections.

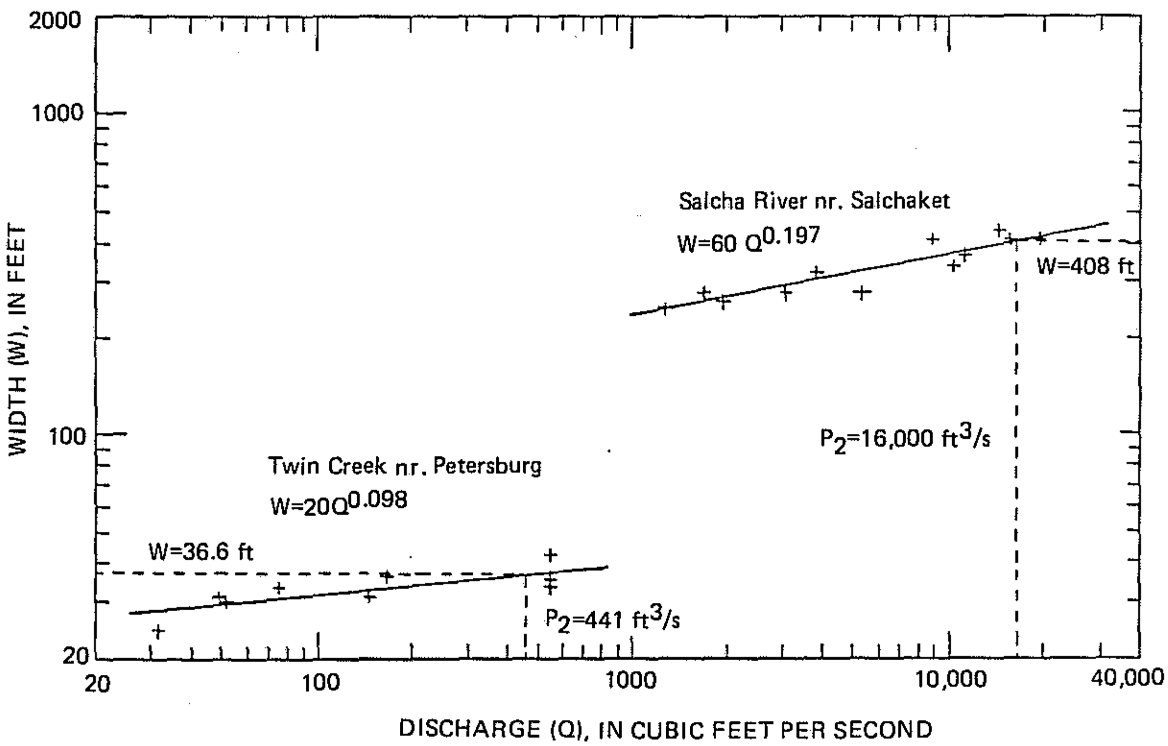


Figure 3.--Example of width determination for two sites. (W, bankfull width; P_2, 2-year peak flow.)

TABLE 3.--Equations using bankfull channel width to predict flood-frequency characteristics for 117 Alaska streams. Subscript for P values indicates recurrence interval of peak.

Peak Value		Equation	Standard Error of Estimate (logs)	(+%)	(-%)	Coefficient of Determination (r^2)
P_2	=	$0.50W^{1.80}$	0.228	69	-41	0.95
P_5	=	$1.17W^{1.70}$	0.206	61	-38	0.96
P_{10}	=	$1.87W^{1.65}$	0.209	62	-38	0.95
P_{25}	=	$3.16W^{1.59}$	0.224	68	-40	0.94
P_{50}	=	$4.50W^{1.55}$	0.241	74	-43	0.93
P_{100}	=	$6.22W^{1.52}$	0.260	82	-45	0.92

The relationship of many hydrologic variables, especially flow characteristics and physical characteristics, is nonlinear. However, these relationships have been found to be more nearly linear if the variables are transformed to logarithms (Benson and Carter, 1973). The general form of a log-transformed regression model is:

$$\text{Log } y = \log(a) + b\log(x)$$

An equivalent expression of the equation is:

$$y = ax^b$$

For this study the regression models were developed using computer programs available from SAS Institute Incorporated (Barr et al., 1979).

Two terms commonly used to describe the accuracy or error in a regression equation are the standard error of estimate (SEE) and the coefficient of determination (r^2). The SEE gives an indication of the variance about the regression and is a measure of the reliability of estimates made from the equations. The coefficient of determination is a general indicator of how well the data fit the equation and, if multiplied times 100, is defined as the percent of dependent variable variation explained by the equation.

It should be remembered that the equations were derived using widths taken from discharge measurements. There is probably an undefinable bias in those widths because cross sections of the measurements may not fully represent a typical bankfull width of the channel reach. Discharge measurement locations may not be the best locations for defining channel characteristics.

Since wading measurements are generally made at sections wider than normal and cableways and boats are used at sections narrower than normal, the equations may tend to estimate low for small streams and high for larger streams. This bias and an additional error in selecting and measuring a representative bankfull width for an ungaged site must be considered when using the equations. The SEE listed, however, is only the standard error of the regression and does not account for these potential errors.

RESULTS

The first set of equations (table 3) is from data for the entire state, and equates each flood-flow frequency characteristic to the bankfull widths. The SEE and r^2 are given for each equation to show the relative accuracy of the regression (SEE's are given in both log units and plus and minus percentages).

Lamke (1979) found that the relation of flood-frequency characteristics to basin characteristics for stations in a maritime climatic environment is different from that for the rest of Alaska. He therefore divided the state into two areas designated Area I and Area II (figure

4), and developed equations for each area based on drainage basin size, mean annual precipitation, lake storage, the mean minimum January temperature, and forested area (Area II). For comparison purposes, equations based on bankfull channel widths were also developed for these same areas (tables 4 & 5). The standard errors associated with Lamke's equations (positive, in percent) are also listed. The standard errors for the two different methods are about the same.

Figure 5 shows the relation of bankfull width to the 10-year peak. This curve is almost identical to a curve shown for Alaskan streams by Riggs (1978, figure 2, p. 90). The curve for Area I is slightly different from the one for the rest of the state, but it is not evident whether the difference between the relations is geographic or morphologic or whether it is simply due to sampling errors. The curve for Area II is so close to the curve for the statewide equation that it could not be shown on the figure.

In an effort to improve the estimating equations, drainage area was added to the analysis and multiple linear regressions were run to equate the peak-flow frequencies to a combination of the width and drainage basin size. However, since drainage area and channel width are so highly correlated, neither the SEE nor the r^2 were significantly improved. Therefore, only equations using the channel width are shown.

CONCLUSIONS

Bankfull width measurements can be used to estimate peak-flow magnitudes and frequencies for streams in Alaska. The method offers an alternative to the use of basin characteristics to determine discharge characteristics for sites on ungaged streams. An advantage this method offers is that values can be estimated quickly from a measurement of bankfull width. The second advantage is that a value for precipitation is not required.

When using the equations, care should be taken to assure that the selected channel reach is free to adjust its width to peak flows and that it is not confined by natural or manmade restraints. It is not recommended to use any of these equations outside the range of observed values from which the regressions were developed because no estimate of error can be made for those ranges.

A measurement of channel width is shown to be useful for estimating peak flows on ungaged streams. And, although the equations given in this report may contain errors because they were not developed from widths measured in the field specifically for this purpose, the analytical method offers a potential for improving our ability to estimate these discharge characteristics.

TABLE 4.--Equations using bankfull channel width to predict flood-frequency characteristics for streams in Area I. (27 sites)

Peak Value		Equation	Standard Error of Estimate (SEE)			Coefficient of Determination	SEE Lamke[1]
			(logs)	(+%)	(-%)	(r^2)	(+%)
P_2	=	$3.02W^{1.46}$	0.156	43	-30	0.87	50
P_5	=	$4.45W^{1.44}$	0.157	44	-30	0.87	48
P_{10}	=	$5.42W^{1.43}$	0.160	45	-31	0.86	45
P_{25}	=	$6.54W^{1.43}$	0.165	46	-32	0.85	48
P_{50}	=	$7.42W^{1.43}$	0.170	48	-32	0.85	42
P_{100}	=	$8.24W^{1.43}$	0.176	50	-33	0.84	--

1. Standard Error in percent for equations derived by Lamke (1979, p. 11) for Area I; is comparable to Standard Error (+%) column in this table.

TABLE 5.--Equations using bankfull channel width to predict flood-frequency characteristics for streams in Area II. (90 sites)

Peak Value		Equation	Standard Error of Estimate (SEE)			Coefficient of Determination	SEE Lamke[1]
			(logs)	(+%)	(-%)	(r^2)	(+%)
P_2	=	$0.40W^{1.82}$	0.214	64	-39	0.97	77
P_5	=	$1.01W^{1.72}$	0.205	60	-38	0.97	78
P_{10}	=	$1.68W^{1.66}$	0.216	64	-39	0.96	79
P_{25}	=	$2.99W^{1.60}$	0.239	73	-42	0.95	59
P_{50}	=	$4.40W^{1.56}$	0.259	82	-45	0.94	68
P_{100}	=	$6.29W^{1.52}$	0.281	91	-48	0.92	--

1. Standard Error in percent for equations derived by Lamke (1979, p. 13-14) for Area II; is comparable to Standard Error (+%) column in this table.

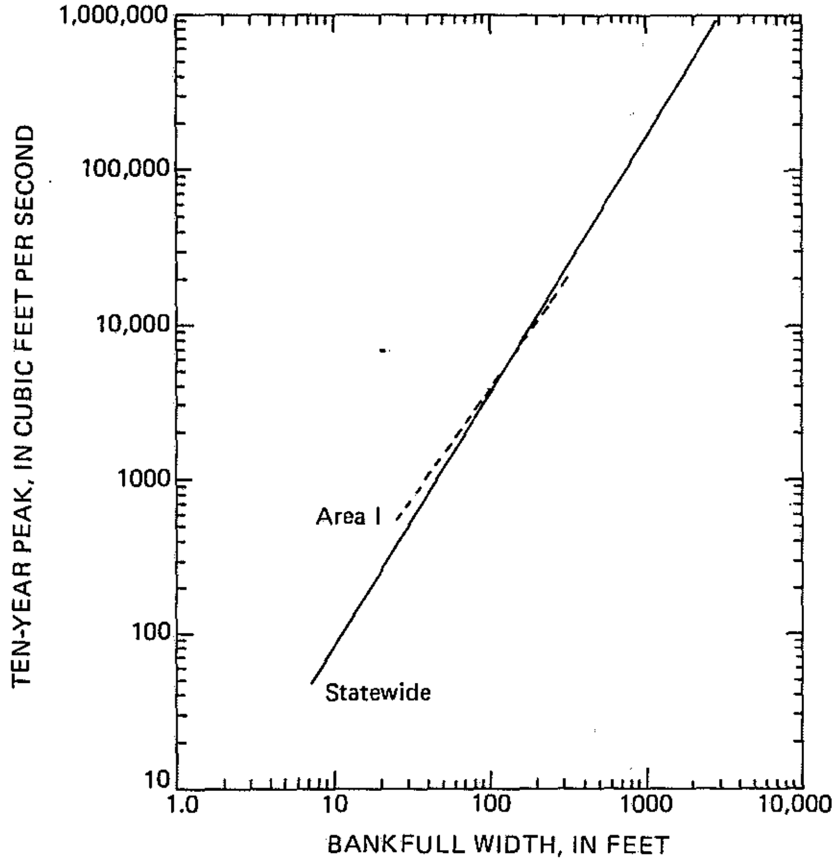


Figure 5.--Relation of bankfull channel width to ten-year peak.

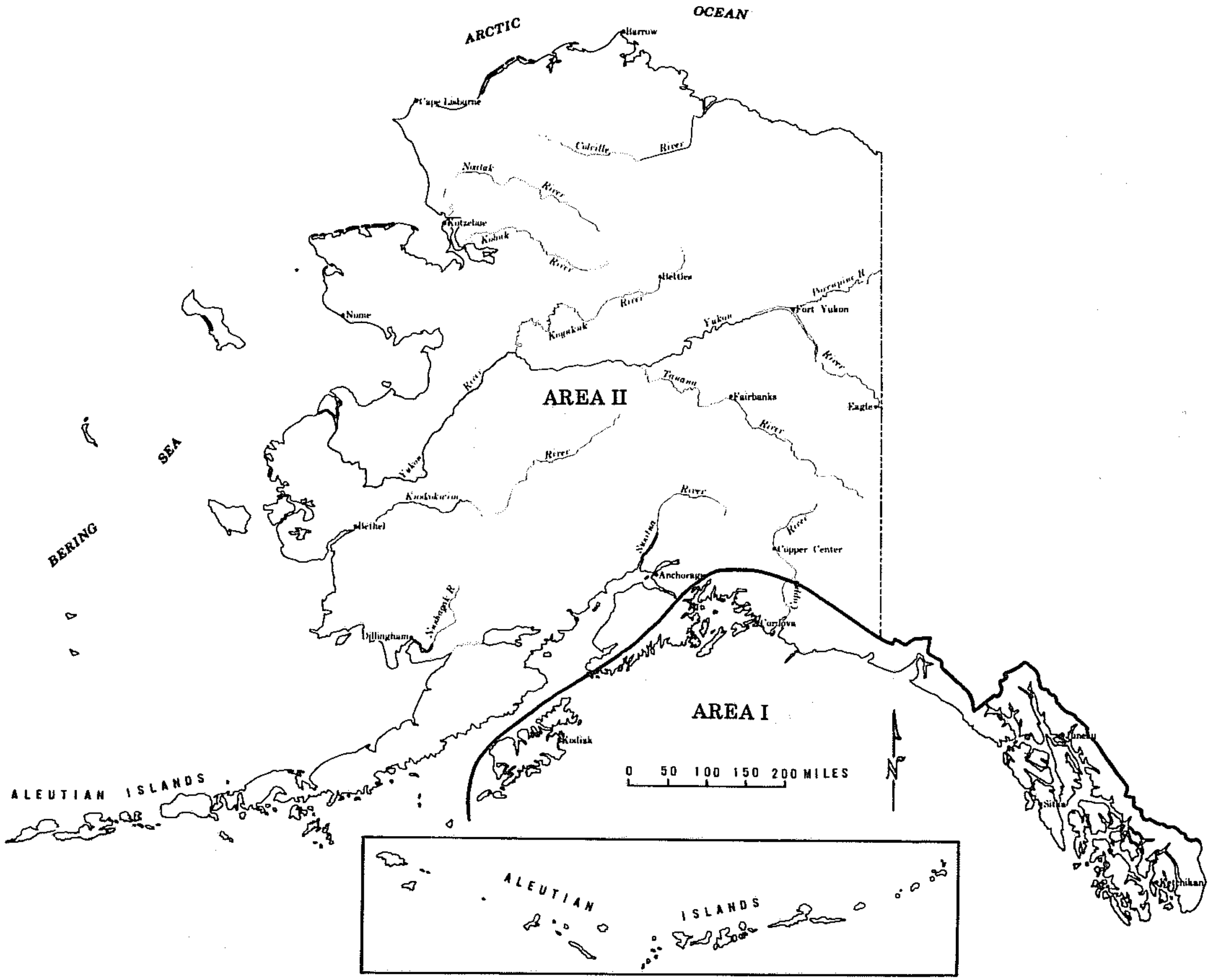


Figure 4.--Location of Areas I and II.

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INSTREAM FLOW

SUPPLEMENTAL GUIDELINES FOR CALIBRATING THE IFG-4 HYDRAULIC MODEL

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ABSTRACT

The U.S. Fish and Wildlife Service Cooperative Instream Flow Service Group (IFG) has developed an innovative hydraulic model based on empiricism and regime theory to assist fishery biologists with quantifying the effects of streamflow alterations on riverine fish habitat. Since its first applications in 1978, the IFG-4 hydraulic model has become the principal method of forecasting site-specific hydraulic conditions when applying the Instream Flow Incremental Methodology (IFIM).

Guidelines for calibrating the IFG-4 model have been published by the IFG. However, experience gained while calibrating several IFG-4 models for a major instream flow study in Alaska indicates that following only the calibration guidelines published by the IFG does not necessarily result in a reliable hydraulic model. Therefore, additional calibration guidelines and validation procedures are being recommended by the authors to supplement those provided by the Cooperative Instream Flow Service Group.

INTRODUCTION

Reliable forecasts of the response of site-specific hydraulic conditions to discharge is of central importance to the IFG microhabitat simulation models. The Cooperative Instream Flow Service Group of the U.S. Fish and Wildlife Service specifically developed two hydraulic models, IFG-2 and IFG-4, during the late 1970's to assist fisheries biologists in making quantitative evaluations of the effect from streamflow regulation on fish habitat. The primary purpose of incorporating hydraulic simulation modeling into the Instream Flow Incremental Method (IFIM) was to make the most efficient use of a limited amount of field data to forecast site-specific instream hydraulic conditions for a broad range of unobserved streamflows.

Both IFG models are based on the assumption that steady flow conditions exist within a rigid stream channel. Streamflow is defined as "steady" if the depth of flow and velocity at a specific location remains constant throughout the time interval under consideration. This

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definition is commonly accepted to mean that the discharge remains constant through the study site during the time interval required to collect a set of calibration data. A stream channel is "rigid" if it (1) does not change shape during the time period required to collect all sets of calibration data, and (2) does not change shape while conveying natural streamflows of the magnitude to be simulated (Trihey 1980).

The IFG-2 model is a water surface profile program (step backwater model) which is based on uniform flow theory and is most applicable to stream reaches with relatively mild gradient and uniform cross section (gradually varied flow conditions). The IFG-4 model is an empirical model based on regime theory and regression analysis which, because of its empirical nature, provides greater latitude for application to stream reaches with non-uniform gradient and irregular cross section (rapidly varied flow conditions). As most often applied, one or two sets of field data are recommended for calibration of the IFG-2 model, whereas a minimum of three data sets are recommended to calibrate the IFG-4 model. Despite its more demanding data requirements for calibration, the IFG-4 model has become the most popular method of forecasting hydraulic conditions when applying the Instream Flow Incremental Method (IFIM).

METHODS

IFG-4 hydraulic models were selected over the IFG-2 model for application to several side sloughs in the Talkeetna-to-Devil Canyon reach of the Susitna River, Alaska. The particular model discussed in this paper was applied at a study site near River Mile 126. The study site contained eleven cross sections and was approximately 1,000 feet in length. Calibration data sets were obtained at slough discharges of 4, 7, 19, and 53 cfs in accord with procedures described in Trihey and Wegner 1981 and ADF&G 1982 and 1983. Field data were reviewed, reduced, and coded for data entry as described in Trihey 1980.

Model calibration was undertaken in accord with guidelines suggested by the IFG (Main 1978 and Milhous et al. 1981). The basic calibration procedure for the IFG-4 model as suggested by the IFG is an iterative process which consists of four steps:

1. Review the input (calibration) data for completeness and ensure that each data set is properly referenced to the appropriate calibration discharge for the study site.

2. Use the IFG-4 program to forecast depths and velocities associated with each set of field data (i.e., simulate each set of calibration data).

3. Review the forecast depths and velocities and examine the velocity adjustment factor (VAF) calculated by the IFG-4 program for each cross section and discharge. If the VAF for all discharges at each cross section is between 0.90 and 1.10 the model is considered calibrated.

The VAF is defined as the ratio between the computed and predicted calibration discharge:

$$VAF = \frac{Q_c}{Q_p}$$

where:

Q_c = computed discharge based on a given set of depth and velocity data for an individual transect (adjusted input data). The mean of the computed discharges is generally used as the calibration discharge.

Q_p = predicted discharge based on the set of forecast depths and velocities at an individual transect (output data) referenced to a particular calibration discharge.

4. If the VAF's are not within the acceptable range, the input data is reviewed and cell velocities or depths adjusted. Steps 2 and 3 are repeated until either the VAF criteria can be satisfied, or no further rational adjustments can be made to the field (input) data.

These guidelines were followed by individuals having limited experience with the IFG models until a "calibrated" IFG-4 model was obtained. The "calibrated" model was applied to predict hydraulic conditions associated with streamflows well within the recommended extrapolation range of the model. Review of the predicted depths and velocities indicated that the "calibrated" model did not provide reliable forecasts. Therefore, supplemental calibration guidelines and validation procedures were developed and the model recalibrated in accord with the supplemental and IFG guidelines. A significant improvement was noted in the reliability of the resulting hydraulic model.

RESULTS

Field data available for calibration of the IFG-4 model at RM 126 consisted of water surface and streambed elevations, and the depth and velocity distribution at each of the eleven cross sections in the study site for calibration flows of 4, 7, 19, and 53 cfs. Following several iterations of reviewing velocity adjustment factors and making minor adjustments to cell depths and velocities, a "calibrated" IFG-4 model was obtained for the study site. The velocity adjustment factors for the eleven transects in the study site and the four calibration flows typically ranged between 0.98 and 1.03. IFG calibration guidelines state that velocity adjustment factors between 0.90 and 1.10 indicate an IFG-4 model is well calibrated (Milhous et al. 1981)

The recommended extrapolation range for a properly calibrated IFG-4 model based on three sets of calibration data is 0.4 times the lowest calibration discharge to 2.5 times the highest calibration discharge (Bovee and Milhous 1978). This particular IFG-4 model was based on four sets of calibration data collected at slough flows between 4 and 53 cfs. Hence, an extrapolation range of 2 to 125 cfs was considered appropriate.

The "calibrated" model was applied to predict water surface elevations and velocities for several slough flows between 2 and 125 cfs. Visual evaluation of the predicted values contained in the computer printouts did not appear reasonable to an experienced reviewer. Therefore, the predicted water surface profiles were plotted in comparison with the surveyed streambed (thalweg) and water surface profiles (Figure 1). This figure indicates the predicted water surface profiles are unreasonable and therefore the model was not as well calibrated as the velocity adjustment factors (calibration criteria) had implied.

Following detailed review of the field data and hydraulic model forecasts, it was decided to divide the four sets of calibration data into two discrete sets in order to account for backwater effects at the higher slough flows; and to develop two IFG-4 hydraulic models for the study site. One model was calibrated using only the 19 and 53 cfs data sets and would be used to forecast hydraulic conditions associated with moderate to high flows (with backwater effects). A second IFG-4 model was calibrated using the 4, 7, and 19 cfs data sets for application to low and moderate flows (without backwater effects). It was also decided to place greater emphasis on using forecast water surface elevations as a guide than velocity adjustment factors during the initial calibration runs. Velocity adjustment factors were not used as the principal calibration criteria until a reasonable forecast of water surface profiles could be obtained for the calibration flows, and the upper and lower bounds of the extrapolation range. Plots of the predicted water surface profiles from the high- and low-flow IFG-4 models are presented as Figures 2 and 3. The maximum difference between observed and predicted water surface elevations at the eleven cross sections in the study site and all calibration flows was 0.02 feet.

The mean discharges predicted by the low-flow model for the eleven transects were 4, 7, and 20 cfs; in comparison to calibration flows of 4, 7, and 19. The mean discharges predicted by the high-flow model were 19 and 53 cfs. Velocity adjustment factors for both models range between 0.95 and 1.03, for the eleven transects across their entire extrapolation range.

Once the IFG-4 models appeared to be calibrated, their reliability was evaluated by comparing forecast and observed water surface elevations, depths, and velocities. A rating curve was developed for a discharge station approximately 1,000 feet upstream of the study site. Water surface elevations forecast by the model at several slough flows were used to develop a comparative curve (Figure 4). Because the two rating curves were not derived for the same location in the slough they are not coincident. However, their slopes are very similar, indicating the hydraulic model is forecasting a rate of change in depth very similar to that observed at the discharge station.

A second indication of the model's predictive capability was obtained from viewing scatter plots of unadjusted depth and velocity measurements (raw field data) and the predicted depths and velocities for the corresponding flows at which the data were obtained. Scatter plots can be produced at various levels of detail. Individual plots may compare measured and predicted values at each cross section by each calibration flow, or, in an overview, may compare measured and predicted values for all cross sections and calibration flows on a single plot. Scatter plots comparing the predicted depths and velocities to observed depths and velocities at all transects in the study site for all calibration discharges are presented in Figures 5 and 6.

DISCUSSION

Use of the IFG-4 hydraulic model has become synonymous with application of the instream flow incremental method (IFIM). Generally the IFG-4 model is used as an integral part of IFG's linked set of aquatic habitat models called PHABSIM. It is the purpose of this paper to underscore the importance of rigorously testing the predictive capabilities of the "calibrated" IFG-4 model prior to using it in a linked fashion with its sister programs.

Experiences described in this paper indicate that whenever the predictive capability of the hydraulic model are not rigorously tested prior to its linkage with other PHABSIM programs, it is quite possible that unreliable streamflow-dependent habitat indices would be forecast by PHABSIM. The supplemental calibration guidelines and validation procedures introduced in this paper are expected to assist users with IFG-4 model calibration. However, they should be viewed as preliminary. These procedures were developed during the model calibration phase of the study to address specific problems by making the best use of an existing data base.

As a result of our experiences it appears desirable to implement field data collection programs for both model calibration and verification. In those instances when field crews can frequently visit in the study site, a stage vs. discharge curve should be developed for at least one cross section within the study site. Three to five discharge measurements and corresponding water surface elevations would be obtained at one transect independent of the calibration data sets. These measurements would be plotted separately to define a stage discharge curve for that specific transect. Water surface elevations at that same transect forecast by the model would be plotted against the rating curve. A well calibrated hydraulic model will forecast water surface elevations throughout its extrapolation range which fall on or very close to the rating curve.

Several opportunities also exist for using the scatter plots as a model calibration tool which have yet to be evaluated. Use of scatter plots during the calibration phase should be useful to critically assess model performance at individual cross sections with regard to a specific set of habitat suitability criteria being applied. For example, the ability of the IFG-4 model to reliably forecast the shallow depths and/or low velocities commonly associated with streambank margins is considerably more important when evaluating flow effects on rearing conditions for immature fish than on spawning habitat for adults. Use of scatter plots is one method of determining whether the "calibrated" model is performing better at low or high discharges, in shallow or deep water, or at low or high velocities. Currently it appears that visual evaluation of comparisons between predicted and observed water surface elevations (stage discharge curves) and scatter plots is more beneficial than statistical evaluations of the differences.

CONCLUSION

The Cooperative Instream Flow Service Group has published guidelines to assist users calibrating the IFG-4 hydraulic model. The authors have determined that adherence to only the IFG guidelines does not necessarily result in a properly calibrated model. Supplemental calibration and validation procedures developed by the authors can significantly improve confidence in the reliability of IFG-4 hydraulic models. These supplemental procedures include:

1. Comparison of predicted water surface elevations (profiles) for the extrapolation and calibration flows to surveyed water surface and streambed profiles.

2. Adjusting field measurements within the limits of reasonable error attributable to field conditions or equipment accuracy.

3. Development of high- and low-flow models.

4. Comparisons of forecast water surface elevations to independently developed rating curves for at least one cross section in the study site.

5. Graphic comparison (scatter plots) between predicted and observed depths and velocities for each calibration flow and transect in the study site.

ACKNOWLEDGEMENTS

This work was completed in conjunction with the licensing studies for the proposed Susitna hydroelectric project. Funding was provided by the State of Alaska, Alaska Power Authority. Field data were collected and computer support provided by the Alaska Department of Fish and Game, Su Hydro Aquatic Studies Team. Special recognition is given Allen Bingham for providing technical advice and developing the on-line computer graphics, without which the validation procedures could not have been tested in a cost-effective manner.

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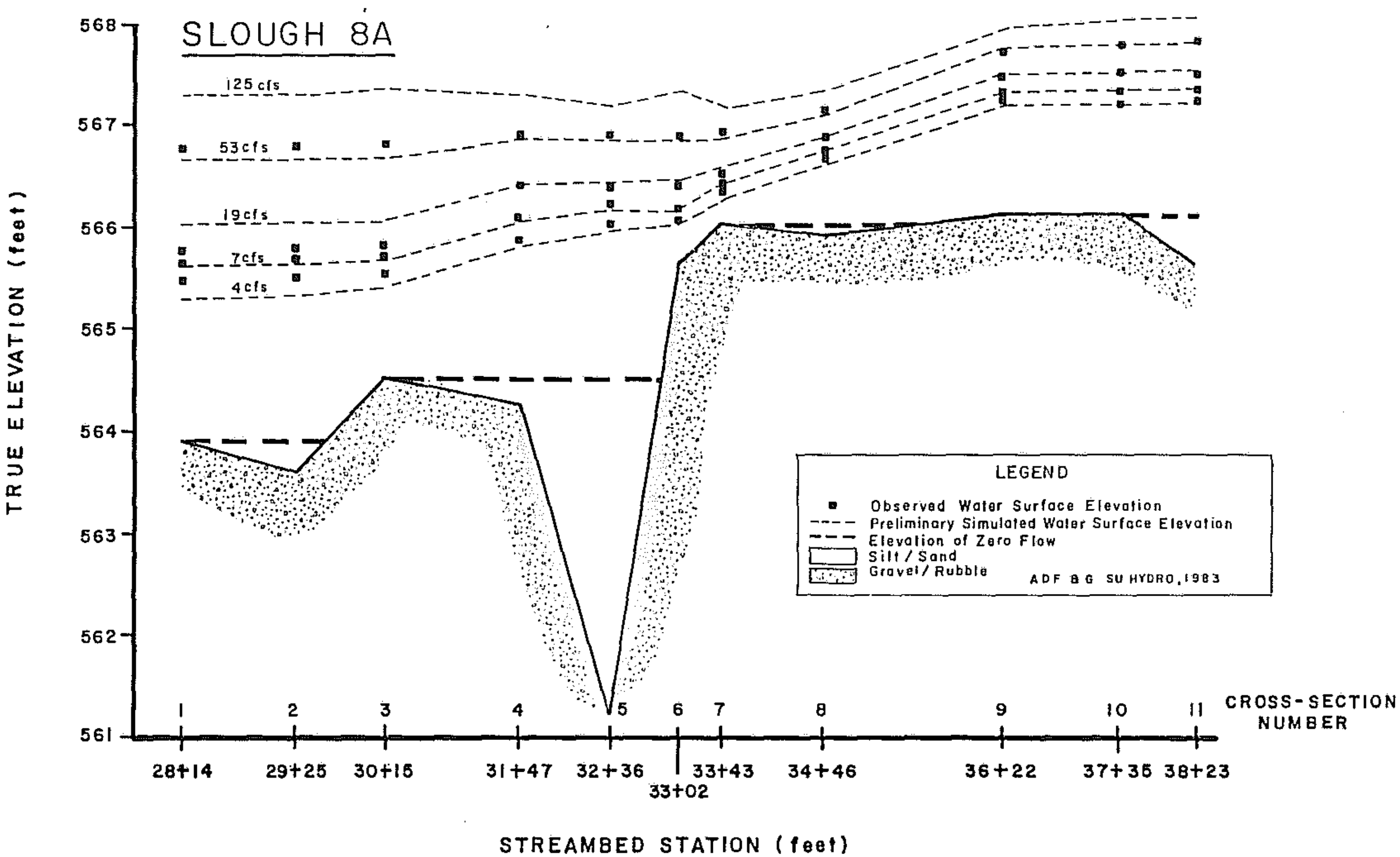


Figure 1. Predicted water surface profiles from preliminary IFG-4 model in comparison to surveyed water surface and streambed elevations.

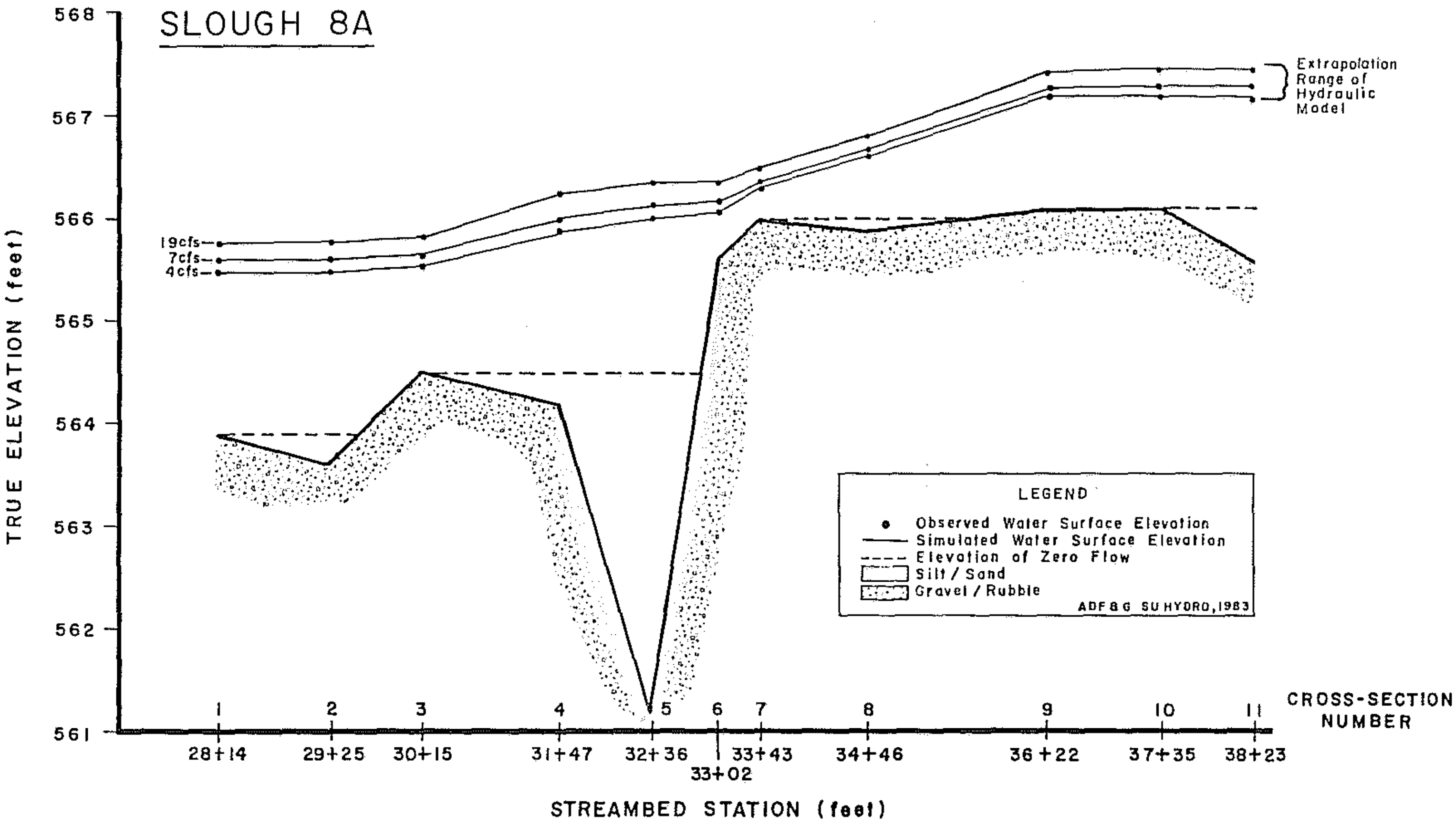


Figure 2. Comparison between predicted and observed water surface elevations at 4, 7, and 19 cfs as forecast by the low-flow IFG-4 model.

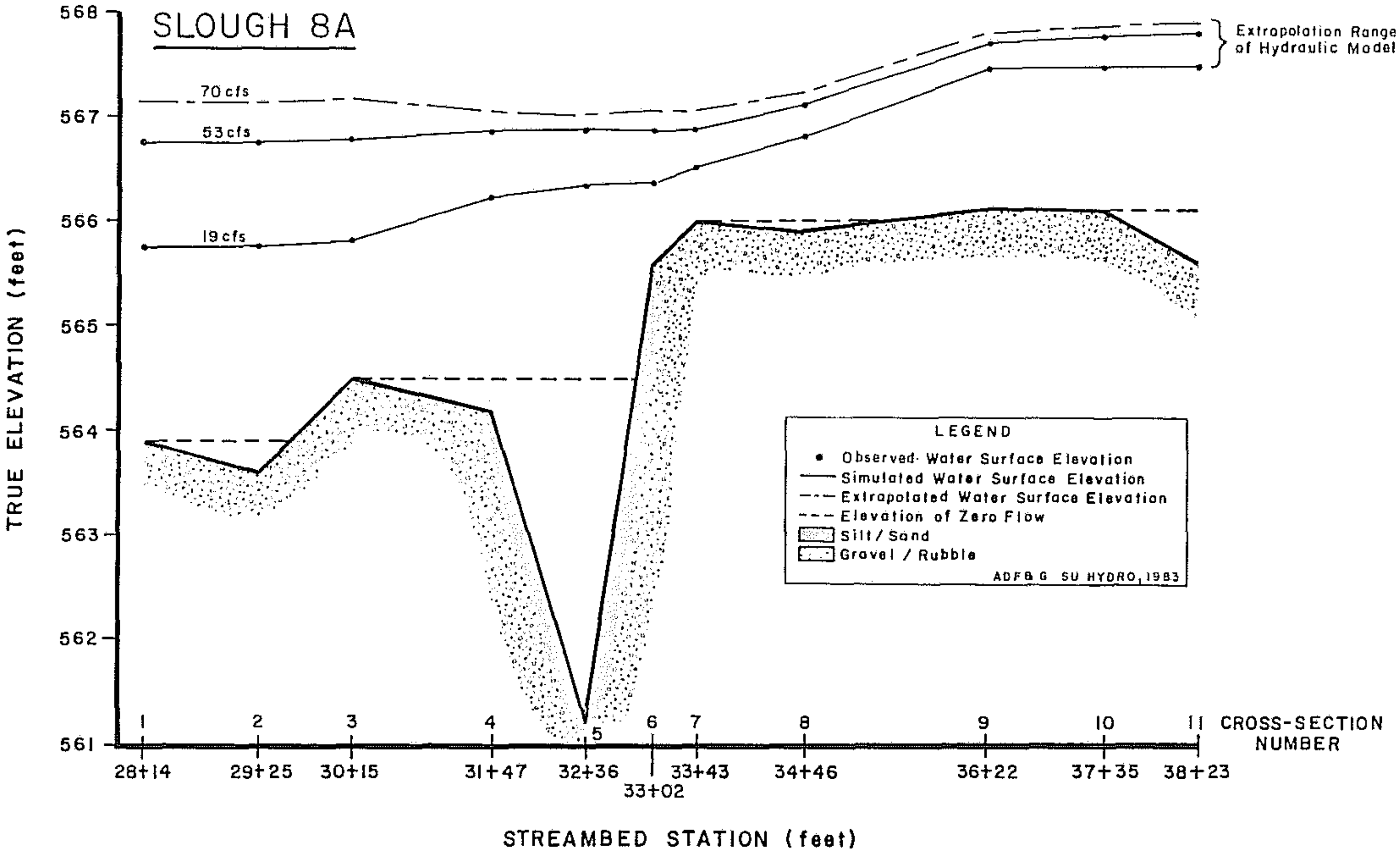


Figure 3. Comparison between predicted and observed water surface at 19 and 53 cfs as forecast by the high-flow IFG-4 model.

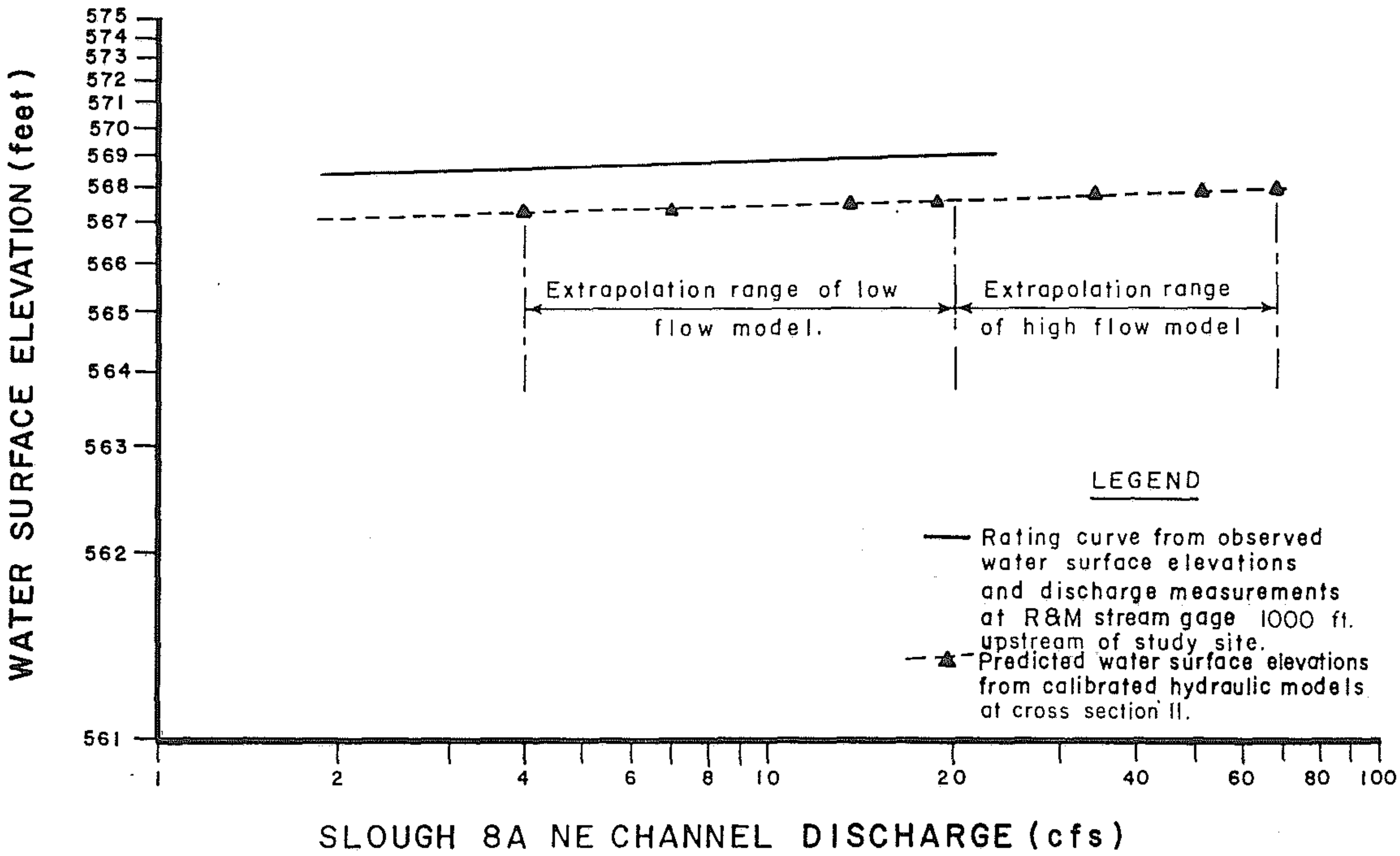


Figure 4. Comparison between predicted and observed stage discharge curves for Slough 8A.

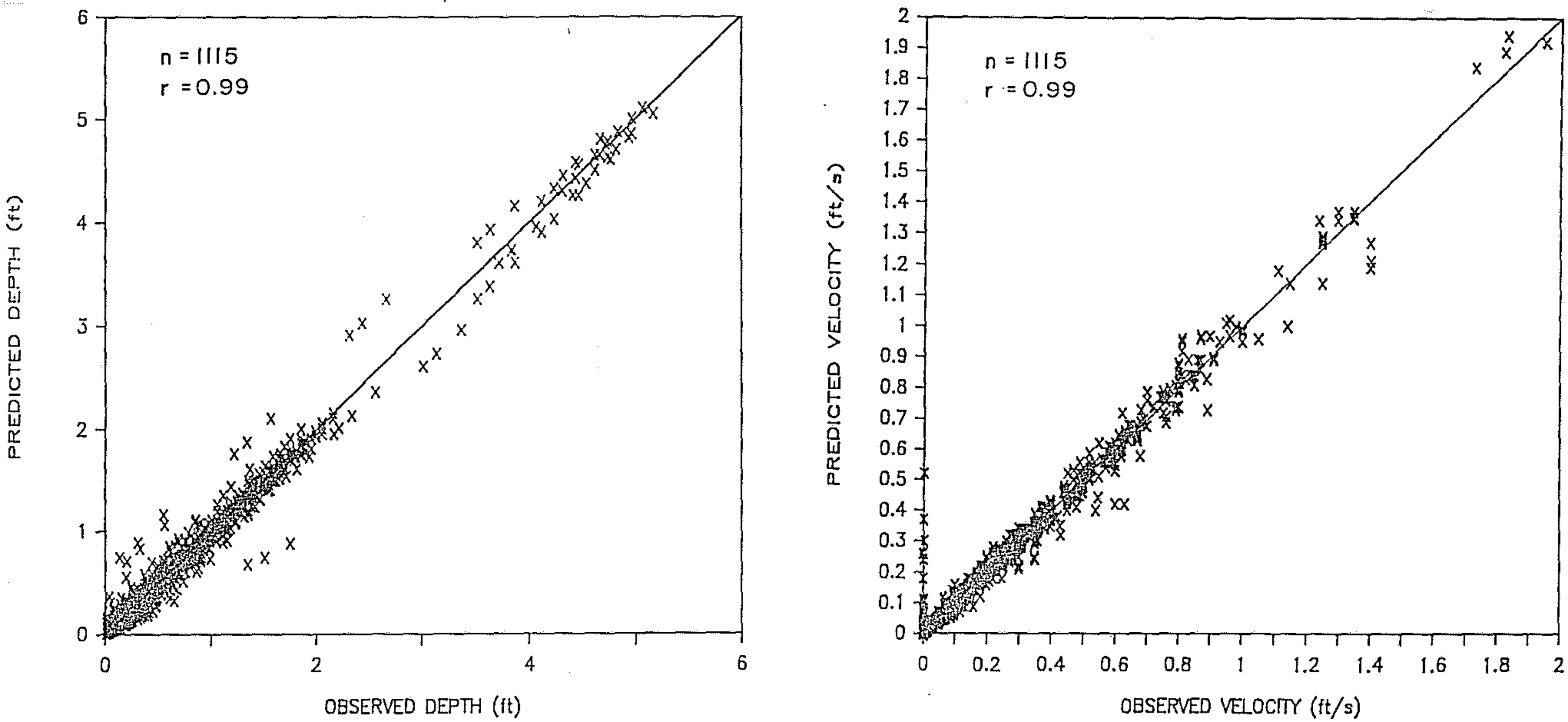
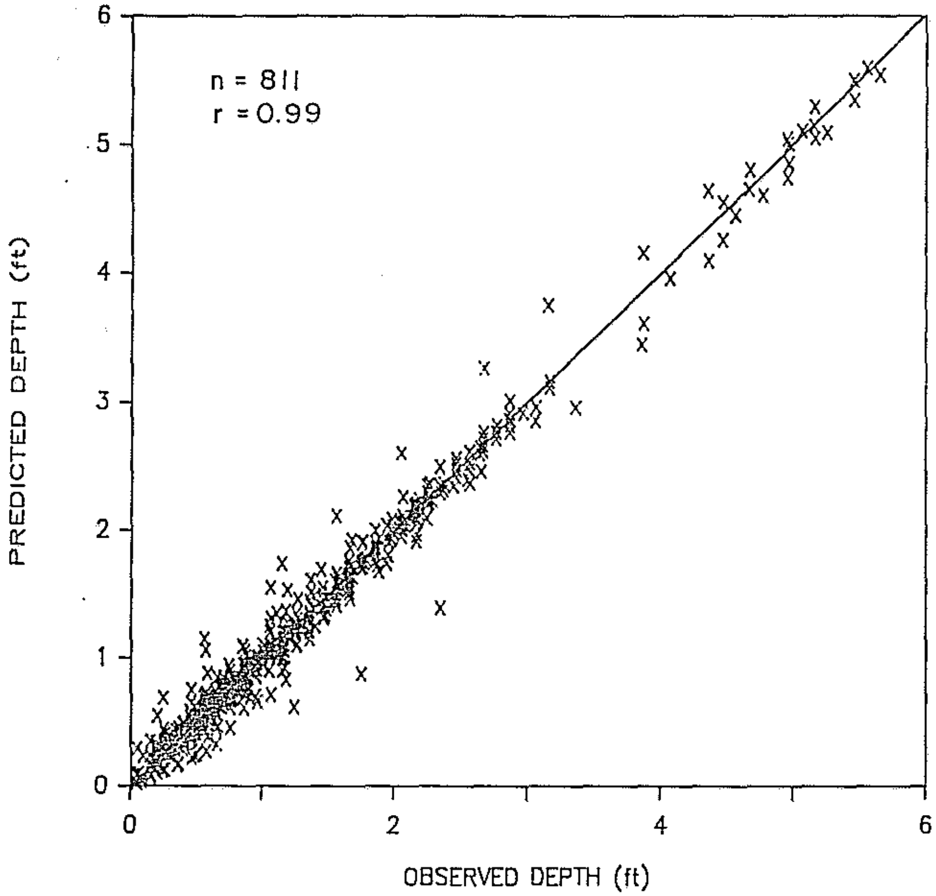


Figure 5. Scatter plot comparisons of depths and velocities within the study site as forecast by the low-flow model at slough-flows of 4, 7, and 19 cfs.



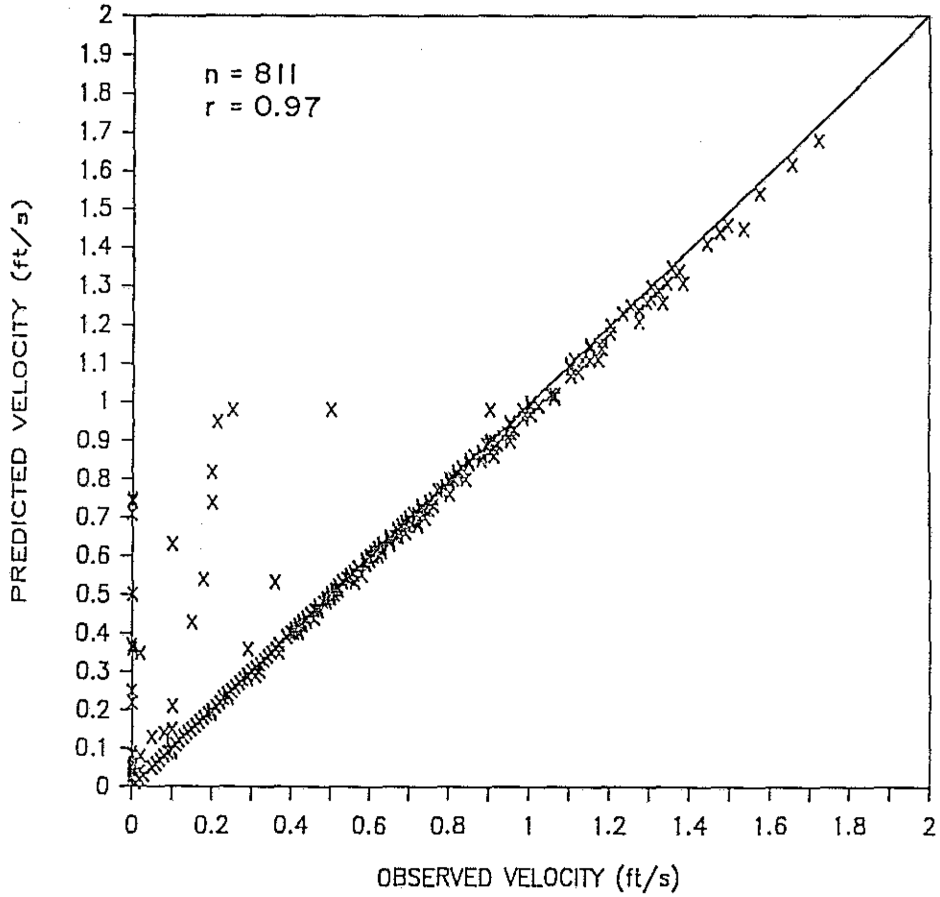


Figure 6. Scatter plot comparisons of depths and velocities within the study site as forecast by the high-flow model at slough-flows of 20 and 53 cfs.

DESIGNING GRAVEL EXTRACTION PROJECTS FOR THE DEVELOPMENT OF GROUNDWATER-FED SALMON SPAWNING AND REARING HABITAT

By J. David Blanchet[1] and Jeffrey W. Saari[2]

ABSTRACT

In a number of cases (most quite by accident), gravel extraction projects on the Chugach National Forest and elsewhere in Alaska have produced desirable salmon spawning and rearing habitat by tapping into usable groundwater flows. Within the last decade a series of projects in British Columbia have focused on development of groundwater resources for salmon habitat and have shown high salmon production rates. Using information from these projects, the Forest Service has been working in cooperation with the Alaska Departments of Transportation and Fish and Game and the Cook Inlet Aquaculture Association to identify, design, and develop appropriate gravel extraction sites. These sites must be suitable for both highway construction needs (acceptable gravels at reasonable haul distances) and fisheries needs (suitable groundwater flows which can be linked to existing anadromous fish streams.) Most of the sites identified are adjacent to glacial streams that currently have poor habitat potential. Project designs for gravel extraction vary considerably depending on the type of habitat desired (spawning vs. rearing) and the species of salmon targeted. Success of these projects may indicate excellent multiple use potential for numerous other gravel extraction projects in Alaska.

INTRODUCTION

Salmon are great opportunists in seeking out acceptable areas for spawning and rearing and at capitalizing on changing stream systems. This is particularly apparent in dynamic glacial drainages in Southcentral Alaska. Individual salmon species are able to focus in on stream reaches which meet their particular spawning and rearing needs most closely. Detailed study of salmon survival success in different stream environments has aided in understanding which stream characteristics are most beneficial to higher natural production rates.

Numerous projects have been designed and built to artificially improve the stream characteristics determined to be the most beneficial to salmon production. These projects have often been on a trial and error basis and have met with varying degrees of success. Several spawning channel projects in British Columbia have had particularly good success and can serve as a model in this area.

In recent years, more attention has been focused on spawning channels whose source is from groundwater springs. The Canadian Department of Fisheries in B.C. has again done innovative work in this area. Their

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groundwater projects serve as a useful working model in designing similar projects in Southcentral and Southeast Alaska, and in explaining the unintentional fisheries success of a series of excavation projects. Ongoing projects on the Chugach National Forest are directed at combining gravel extraction with development of groundwater-fed salmon habitat areas. Through interagency cooperation, fisheries enhancement projects are being accomplished at little cost to the Forest Service other than site inventory and project design.

HISTORY

Efforts have been made for over 100 years to increase the abundance of the Pacific salmon. The success of different techniques has not always been apparent due to large natural fluctuations in salmon populations (Larkin, 1974). Initial population enhancement techniques were directed largely towards development of hatcheries and hatchery stocks. This approach has often been quite successful, but has also reduced the genetic viability of certain fish stocks by limiting the role of natural selection in the breeding and development process.

In the 1940's and 50's fisheries biologists began developing the idea of increasing salmon abundance by altering stream characteristics to more closely fit the specific spawning and rearing needs of a targeted salmon (or trout) species (Bevan and Kippola, 1962). Characteristics altered include: flows, flow velocities, and channel substrate, dimensions and cover. The "spawning channels" created allow for natural selection within the salmon stocks, but can greatly improve both the available spawning area and egg to fry survival rates.

In the past 30 years a number of spawning channels have been developed in streams along the Pacific Coast from California to Alaska. Effectiveness of these channels has been variable. On the Fraser River in British Columbia, several notably successful spawning channels have been constructed, resulting in sustained high salmon returns over a number of years (Cooper, 1977). These channel projects are on a relatively large scale and have required a large initial capital outlay and considerable annual maintanence costs.

A number of spawning channels have failed to function adequately or continuously. In some cases channel failures have been caused by streams returning to their former condition due to flooding and/or erosion. A spawning channel built on the Indian River at Prince of Wales Island in Southeast Alaska suffered this fate when it was flooded out shortly after construction during the summer of 1961 (Bevan, 1964). Other spawning channels have been constructed which inadequately assessed the habitat needs of the targeted salmon species and consequently have shown low productivity.

In the 1970's the Canadian Department of Fisheries in B.C. began to explore the development of groundwater-fed spawning channels. A number of these channels have been built in the Vancouver, B.C. area. An Alaskan groundwater-fed spawning channel was constructed in 1983 near Haines, Alaska by the Northern Southeast Aquaculture Assoc.

These channels have all been targeted to chum salmon. Chums are known to prefer spawning areas with upwelling groundwater flows.

Spawning channels in B.C. have been developed by selecting sites where groundwater springs appear at the surface and then link back into an existing chum salmon stream. These sites require protection from flood flows and the presence of permeable sands or gravels (to allow for sufficient flows.) Several of the groundwater channel sites in B.C. are located behind flood control dikes (on preexisting floodplains) and reconnect back to the mainstem. These channels are improved in depth, flow velocity, substrate, and when possible, flow quantity, for greater suitability to spawning chum salmon. Groundwater-fed channels have the advantages of providing streamflows with minimal fluctuations, and low sediment loads and potential for freezing. Maintenance needs are also low.

Lister et al. (1980) diagrams and explains seven groundwater-fed habitat projects in B.C. and details their egg to fry survival rates. These projects have increased salmon productivity by increasing available spawning area and improving egg to fry survival rates. Survival rates (average 16.3%) are generally about twice those found under natural spawning conditions. Several sites have coincidentally provided rearing habitat for coho salmon fry. Relative to larger spawning channels, groundwater projects have been built with low initial investment costs and have demonstrated high benefit cost ratios. Individual projects vary in their degree of success and demonstrate the need for careful site selection.

Groundwater-fed sites have also been used for development of egg incubation boxes in B.C. Here, fertilized salmon eggs are implanted into a gravel filled box which has a steady groundwater supply upwelling through it. Following incubation and hatching, newly emergent fry migrate from the boxes to nearby streams. These projects are conceptually very similar to hatcheries, but require far lower construction and maintenance costs. In some cases incubation boxes may be used temporarily to establish salmon into a given stream drainage and the water source can be later converted to a groundwater spawning channel.

UNINTENTIONAL DEVELOPMENT OF GROUNDWATER-FED FISHERIES SITES

This section outlines nine sites, mostly in Southcentral Alaska, where groundwater habitat areas have been developed unintentionally. In most of the cases, habitat was created when groundwater was tapped during the course of excavation on inactive floodplains. Excavation effects on fish habitat have been quite similar to groundwater habitat projects in B.C., with the exception that increased salmon productivity was not at all the initial intent. Southcentral Alaska is particularly prone to this situation due to the existence of numerous stabilizing outwash plains on receeding glacial systems. Outwash plains are often a rich source for both gravels and groundwater flows (see the next section on Desirable Criteria.) Excavations have unintentionally created both effective spawning channels and rearing ponds. The sites discussed below are not a complete list, but are intended to display several groundwater-fed habitat sites that were developed in a variety of different ways.

Portage Valley gravel pits. Portage Valley near Girdwood, Alaska is an excellent example of a stabilizing glacial stream system. Portage Lake began forming in the upper end of the valley in the early 1900's with the recession of Portage Glacier. The lake acts to stabilize Portage Creek by greatly attenuating flood peaks and by trapping the glacial sediment load which was formerly carried and deposited downsteam. Numerous gravel pits have been excavated in Portage Valley for construction and (earthquake) reconstruction of both the Seward Highway and the Alaska Railroad. The valley is an excellent source of alluvial gravels and has a shallow groundwater table. Many of the gravel pits now form groundwater-fed ponds with channels connecting back into Portage Creek. These channels and ponds have become spawning and rearing habitat for chum, sockeye, and coho salmon, and in some cases provide very ideal habitat.

Resurrection Creek placer mines. Pink salmon have been observed spawning in channels and settling ponds of inactive mining operations on Resurrection Creek near Hope, Alaska. These operations are located on the former floodplain of the river and often have good groundwater flows as well as good quality spawning gravels. The degree of success of these sites for salmon habitat has not been well established, and in several cases the resultant fish habitat has been altered by renewed mining activity.

Valdez Glacier outwash plain. Two groundwater-fed habitat areas were developed near the Valdez Airport on the outwash plain of the Valdez Glacier (Mattson and Perkins, 1978). This outwash plain is quite similar to Portage Valley; including a rapidly stabilizing glacial stream system which emerges from a lake formed by the recent retreat of a valley glacier. Groundwater occurs at a shallow depth.

During excavation of gravel for the Valdez area after the 1964 quake, a pit was developed at a depth of 5 to 8 feet which penetrated the groundwater table. A groundwater-fed stream (Loop Road #141 Creek) pre-existed downslope of the pit and has been used by pink salmon for spawning. Creation of the pit increased both the available spawning area and the flow rates to the creek, thus allowing native salmon stocks to increase in abundance.

In the fall of 1974 an interceptor trench was built around the Valdez sewage treatment plant (also located on the outwash plain) to prevent surface flows from entering into the area. During excavation, the groundwater table was penetrated, producing flows between 5 and 10 cfs in the interceptor trench. Despite the relatively poor quality substrate, pink salmon began using the trench for a spawning channel. Mattson and Perkins (1978) collected detailed data on flow, water quality, and salmon escapement from this site and at Loop Road #141 Creek. This data has been useful in defining fisheries potentials at both sites.

Fivemile Pit Creek on the Lowe River. This is a gravel pit site developed for highway reconstruction near Valdez after the 1964 quake. It lies on a terrace and former floodplain of the Lowe River and is fed by lateral groundwater percolation from the Lowe River. The resultant pond and the stream reconnecting it to the Lowe, are used for spawning by pink and chum salmon. The pond is used for rearing by coho fry. Water and fisheries data have been collected at this site (Mattson and Perkins, 1978).

Flood control dike on the Sheridan River. A flood control dike was built along the east side of the Sheridan River at Mile 18 of the Copper River Highway near Cordova. This dike was built to entrain flood flows from the Sheridan under a single highway bridge rather than spilling into alternate channels which cross over the highway. Construction resulted in flood protection of a groundwater-fed channel behind the dike. A small coho salmon fisheries has established itself in this stream. Additional spawning area could easily be developed through excavation at this site, however, predation on salmon by other fish appears to be a significant fisheries problem here.

Scott River near Cordova. The Scott River is a very actively aggrading and braiding glacial stream which flows out from underneath the Scott Glacier. The river shows frequent lateral shifts in its departure point out from under the glacier. The river also shifts in the primary channels that it occupies within the valley. Although the Scott is an unstable, sediment-laden river, the valley is used heavily for spawning and rearing by coho salmon. Abandoned stream channels within the Scott River Valley often tap into the groundwater table and provide moderated, low sediment flows which attract spawning and rearing coho salmon. If primary flows from the Scott River switch back into one of these groundwater-fed channels, then the salmon using that channel will seek out another groundwater rivulet to use instead. A dynamic process of groundwater channel destruction and creation continues on the floodplain.

Yakatat Airport. Deep drainage ditches were excavated around the perimeter of the Yakutat airport during its construction in World War II. These ditches penetrated the water table and developed adequate flows to attract and maintain spawning coho and pink salmon stocks (Mattson and Perkins, 1978). The Yakutat Forelands where the airport is located is an alluvial deposit and the former outwash plain of the Malispina Glacier. No glacial flows presently cross these forelands and groundwater recharge is due strictly to precipitation, which has been sufficient to maintain flows along the airport ditches.

East Fork Bradfield River gravel pit. This is another unintentional groundwater pond and channel developed on a previous river floodplain (of the East Fork) and receiving groundwater input from both the river and its sideslope. The pit was excavated in 1976-77 to obtain gravel for timber road construction. During its development the pit filled with water. A channel was later built out of the pit to lower its water level after a backhoe used for excavation accidently fell in. The pond has since been observed to be a rearing area for coho salmon fry (Russell and Schramek, 1983.)

DESIGN CRITERIA FOR GROUNDWATER-FED SPAWNING CHANNELS

Information from both intentionally and unintentionally developed groundwater-fed channels and ponds in British Columbia and Alaska has been useful in identifying and evaluating sites with groundwater potential. Southcentral Alaska has numerous glacial outwash plains and valleys (associated with receeding glacial systems) that often have rich sources of alluvial gravels and shallow water tables. A list of criteria used for initial selection of groundwater-fed channel sites on the Chugach National Forest is listed below. Criteria vary to some extent depending on the individual site and the salmon species targeted.

1. Excavation should occur in primarily coarse, permeable materials. Gravels are ideal, and cobbles and/or sand can be acceptable. Finer materials (silts and clays) do not allow for good transmission of groundwater flows and are unsuitable for channel base material or for spawning substrate.

2. The local water table must maintain a level relatively close to the ground surface. If the water table is far below the ground surface, then extensive amounts of excavation are neccessary for development of fisheries habitat. Excavation costs can make fisheries habitat development prohibitively expensive. Deep excavation can also cause problems in connecting the work site back to the main channel.

If the groundwater table fluctuates a great deal, a developed habitat area may go dry for periods of time. Sometimes this problem can be resolved by sealing the bottom of a groundwater channel off (ie. with plastic or clay) downstream from the groundwater source area. In this instance, streamflows remain perched above the water table rather than sinking down below ground.

3. The groundwater channel must be protected from significant flooding events. This criteria seperates out many areas that otherwise have good potential for developing groundwater-fed habitat. Logic for the criteria should be apparent: if developed habitat sites are exposed to major flood events, they may be altered or destroyed. Desirable areas for habitat development are often those that were active floodplain in recent time, but because of reduction in stream flows and/or sediment loads have become stabilized and flood-protected. Stabilizing streams originating from receeding glaciers such as at Portage and Valdez are excellent examples. Another possibility for good groundwater sites is floodplains which have been artificially protected from flood flows by dike construction.

4. Groundwater channels should tap water from systems with poor habitat potential (and not from systems with good fisheries production.) Both unstable glacial streams (with heavy sediment loads) and high gradient tributaries often provide only minimal fish habitat and are good sources to tap groundwater from. Groundwater flows are advantageous for salmon habitat in that sediments are largely sorted out and flow and temperatures fluctuations are moderated. Groundwater channel slopes and dimensions can be adjusted during site development.

5. The mainstem channel should not be actively downcutting. If the mainstem is downcutting, the water table will be lowered along with the stream. A groundwater channel which feeds into the mainstem will eventually be left high and dry as its flows go subsurface. This can be resolved in part by reexcavating the groundwater channel at the same rate that the mainstem is downcutting. However, this requires considerably increased maintenance costs.

6. Sufficient groundwater must be available. Availability of groundwater is dependent largely on drainage area and annual precipitation. Groundwater-fed spawning channels should develop at least 5 to 10 cfs in order to provide sufficient habitat (Mattson, 1978). Flows less than this may be undesirable for spawning habitat but usable for development of rearing habitat (ponds and sloughs.)

7. Existing groundwater systems are often the best development sites. A good example is abandoned flood channels which currently have groundwater flows linking back into the mainstem channel. These systems can be readily deepened, widened, lengthened, and increased in flow, consequently increasing habitat area.

8. Problems. A number of different problems are associated with groundwater-fed habitat areas. These problems must be considered when designing new habitat areas, and include:

* Silting of the channel and algal growth due to low stream velocities.
* Loss of surface flows during low flow periods.
* Flood damage due to encroachment of unexpected high flows.
* Winter freezing problems if flows or water depths are inadequate.
* Loss of groundwater source (due to shifting or downcutting of the mainstem channel.)
* Predation of salmon eggs and fry by other fish.
* Alteration of developed channels by beavers.
* Low dissolved oxygen levels in the groundwater.
* Site materials are the wrong grade for construction needs.
* Channel substrate is an inapproriate size for spawning.
* Heavy recreation pressures due to accessibility of developed areas.

Most of these problems can be resolved in the design and maintenance of a project. In many cases it is useful to predict the possibility for these problems to occur prior to completing project designs.

GROUNDWATER-FED HABITAT AREAS CURRENTLY BEING DEVELOPED

Two groundwater-fed spawning and rearing habitat areas are currently being developed on the Chugach National Forest in the process of extracting gravel for reconstruction of portions of the Seward highway. Design and implementation of these projects has been coordinated through the Forest Service, the Alaska Departments of Transportion and Fish and Game, and the Cook Inlet Aquaculture Association. One of the sites is located in Portage Valley on an existing groundwater-fed stream (Williwaw Creek) and the other site is situated in Turnagain Pass adjacent to the confluence of Lyon and

Granite Creeks. These projects both have the advantages of providing a gravel source at a close haul distance from the highway reconstruction (at Turnagain Pass). At the close of the projects the gravel extraction areas will be contoured into a system of rearing ponds and spawning channels rather than leaving empty gravel pits. These projects do create some additional problems and costs for the highway builder (largely the problem of mining gravel underwater), however, these costs are offset by benefits to both sports and commercial fishing interests. An explanation of the two sites follows.

Williwaw Creek Site

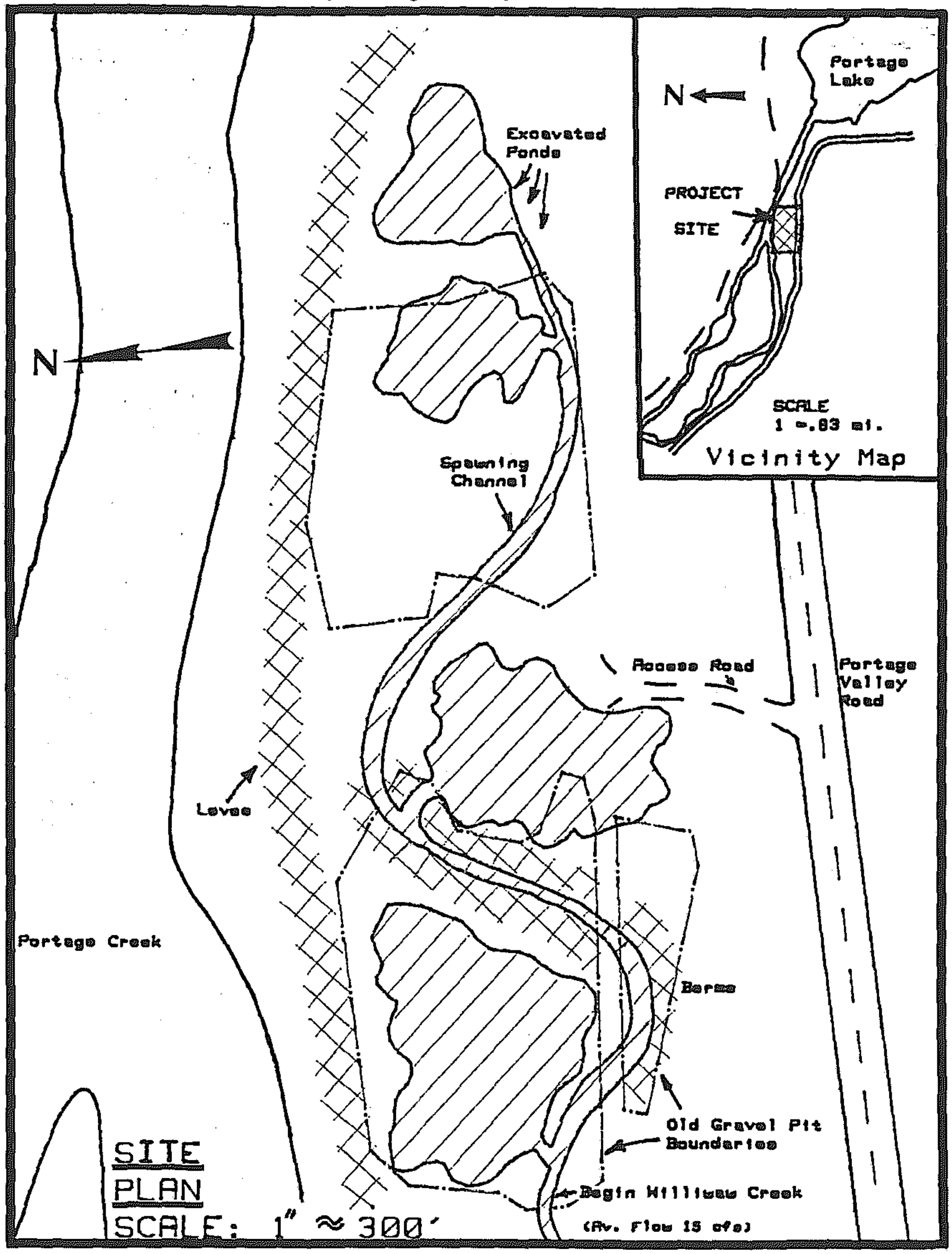
This site is "proven" in that it is a former gravel extraction site (dating back to post-earthquake highway reconstruction.) Groundwater moves into this gravel pit (the headwaters of Williwaw Creek) both horizontally from Portage Creek, and vertically by upwelling from the water table. Sockeye and chum salmon use Williwaw Creek for spawning. Sockeye use the shallow pond in the gravel pit for spawning and to a small extent for rearing. Coho also make light use the creek for spawning and rearing. Streamflows and available spawning area were both considerably increased on Williwaw Creek by the development of the gravel pit in 1964. Flows on Williwaw Creek are very stable year-round, varying from about 15 to 30 cfs at the highway bridge (except during very high water conditions when other channels can spill over into Williwaw Creek.)

The current project at the Williwaw Creek gravel pit involves the extraction of about 200,000 cubic yards of gravel from this site. After completion of the gravel extraction and rehabilitation of the site, Williwaw Creek will be increased in length and will be connected to series of rearing ponds. Pond design allow for flexibility in the quantities of gravel taken. The project will tap into additional groundwater from Portage Creek. Figure 1 displays the site plan for the Williwaw project. Increased flows and increased channel and pond area should work to enhance coho, sockeye, and chum salmon populations in the stream system.

The site fits very closely to criteria outlined in the previous section. Williwaw Creek is located on the stabilized outwash plain of Portage Glacier. Less than 80 years ago the glacier was advanced to the outlet of what is now Portage Lake. At this time the valley below the glacier was filled with braided stream channels. Flood flows and sediment loads down the valley were very heavy. As Portage Glacier has receeded back into the lake, flood flows have diminished greatly (due to flow attenuation) and sediment loads have decreased to a low level. Channels in Portage Valley have stabilized remarkably with the glacial recession. Areas such as Williwaw Creek which were formerly subjected to extensive flooding alterations are now protected.

Since spawning salmon in Williwaw Creek are a very popular attraction to Portage Valley visitors, this project has great benefits to the Forest Service recreation program, as well as to commercial fishing interests and to reconstruction efforts on the Seward Highway.

FIGURE 1. Spawning channel and rearing pond design at Williwaw Creek near mile 4.5, Portage Valley Road.



Lyon Creek Site

This project is similar in design to the Williwaw Creek site. It involves the lengthening and deepening of an existing groundwater channel and development of adjacent ponds. The project is situated on the stabilized floodplain/outwash of Lyon and Granite Creeks which is not currently subject to flood damage. Groundwater flows are intercepted from the hillslope above the project area and from Lyon Creek itself. Gravel extracted from the site has been used for reconstruction of the Seward Highway in the Turnagain Pass area. The project has been designed with a stronger emphasis on development of rearing habitat (ponds) than of spawning habitat (channel). Coho salmon are the primary target species, although incidental benefits may accrue to king salmon as well. Upper Granite Creek is currently being stocked with coho fry and stocking may continue in the new ponds.

Problems were encountered on this project in September of 1984 when fill material being extracted from the site was found to be too high in silt content. A number of test pits showing acceptable fill material were dug previous to construction. However, excavation during the project indicated that several silt stringers run through the site which had gone undetected during testing. Since excavation was being done underwater, segregation of these silt stringers was not possible and fill excavation had to be discontinued. Alaska DOT still plans to rehabilitate this site for salmon enhancement, but likely not to the extent that was originally planned.

CONCLUSIONS

Developing groundwater-fed salmon spawning and rearing habitat in concert with gravel extraction projects has proved to be effective in increasing salmon populations at a number of Alaskan sites in the past. Two projects on the Chugach National Forest are presently attempting to optimize this process during reconstruction efforts on the Seward Highway. The Forest Service is working actively with the Alaska DOT in identifying additional sites with both gravel extraction and fisheries enhancement potential that can be used on future highway reconstruction projects. In addition, the Forest Service is evaluating fisheries enhancement potential on other gravel extraction projects unrelated to highway reconstruction and also on completed placer mining operations on the Kenai Peninsula.

Design and development of groundwater-fed spawning channels involves a facinating synthesis of groundwater hydrology, glacial geomorphology, fisheries biology, hydraulic engineering, and project economics. As new projects are developed, more and more is being learned about which techniques work the most effectively. Project site selection, design, development, and maintenance are definitely not without problems, and generally require an integrated resource approach to determine how to best meet a variety of needs. Multiple use benefits that accrue from such projects are excellent, and help to encourage both refinement of the process and expanded development of its use.

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WATER QUALITY

THE PERSISTANCE OF SELECTED BRUSH CONTROL HERBICIDES IN ALASKAN SOILS NORTH OF LATITUDE 60 DEGREES N

by William Burgoyne[1] and Herbert Rice[2]

ABSTRACT

Although more than a decade has passed since the end of the Viet Nam War, public concern over civilian use of phenoxy herbicides identified with "Agents" Orange, Blue and White has increased. Aware of this, between 1976 and 1980 the Alaska Department of Transportation and the Alaska Railroad cooperated with the Alaska Department of Environmental Conservation in a study to evaluate the persistance of these compounds in a sub-arctic environment.

In 1981 and 1982 field tests and an analysis of soil samples from triclopyr sprayed plots along the Alaska Railroad demonstrated that this compound is as effective on problem brush species as was a mix of 2,4-D and picloram. Although the newer compound is more persistant than the earlier mix, it was judged less likely to migrate in surface and ground water and appears more acceptable to an environmentally concerned public than are the compounds associated with military applications.

INTRODUCTION

Modern brush control in the State of Alaska, through the decade of the 1970's, has largely depended upon the phenoxy herbicides 2,4-D (2,4-Dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-Triclorophenoxy acetic acid), the former compound often formulated in combination with the herbicide picloram (TORDON 101(R). With the banning for most purposes of 2,4,5-T in 1978, 2,4-D was substituted in Alaska for right-of-way vegetation management (Alaska Department of Environmental Conservation, 1976-1983). Public concern for the acute and, possibly, chronic effects of a byproduct of the phenoxy herbicide manufacturing process, dioxin or TCDD (2,3,7,8-tetrachloro-dibenzol-p-dioxin) peaked in the late 1970's, and fueled by revelations of hazardous waste misuses in many states, this concern has remained high through the present time (Council for Agricultural Science and Technology, 1978). This is especially true for the environmentally aware citizens of the State of Alaska.

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Although a series of soil residue analyses in 1978 and 1979 indicated 2,4-D did not persist in any of our plots beyond one year, the unsavory image of the "Agents" continued to be associated with commercial formulations of the phenoxy herbicides and our studies were expanded to search for compounds that might be more environmentally acceptable in Alaska.

In 1981, cooperating with the Dow Chemical Company, the engineering department of the railroad and the pesticide office of the Department of Environmental Conservation (ADEC) decided to investigate the suitability of a relatively new brush control agent, triclopyr (3,5,6-tricloro-2-pyridinyloxy-acetic acid, butoxyethyl ester) as a substitute for the controversial 2,4-D. The product is marketed by the Dow Chemical Company under the trade names GARLON 3A(R) and GARLON 4(R). Spray techniques and sampling procedures were designed to duplicate those used in the earlier studies as nearly as possible. Our goals were to evaluate the persistance of triclopyr in Alaskan soils and determine its efficacy for controlling local species of woody brush. Viereck and Little (1972) describe 20 species of willow and three species of alder from terrain crossed by the route of the Alaska Railroad. Other problem species are raspberry, paper birch and several members of the wild rose family. Although not usually a species to be controlled, black spruce (Picea mariana) was sprayed in several areas to judge its resistance to the herbicide.

METHODS

Experimental design perimeters used in our testing of these herbicides were established with the selection of the first series of test plots in 1978. These were:

To work mainly with the herbicides TORDON 101, a mix of 2,4-D and picloram used for right-of-way spraying by many state and federal agencies;

To set plots in two areas of the state traversed by the Alaska Railroad: interior and southcentral Alaska;

To sample soils and analyze for pesticide residues at periods of approximately two hours, two days, two weeks, two months and one year after application of a label-recommended dosage;

To test for efficacy and persistance in the northern environment formulations that might be substituted for the controversial phenoxy compounds.

Spray equipment was provided by both the Alaska Railroad and the Alaska Department of Transportation, Division of Highways. The 1978 plots were located along seldom used service roads on the Anchorage and Fairbanks International Airports and at mile 162 of the railroad near the town of Wasilla. All sites had no history of being treated with herbicides.

Prior to spraying, controls were taken at the test site. At three locations treated in 1978 and the one location sprayed in 1979, holes were dug to a depth of eight inches at three randomly selected sites and a soil mix placed within a single glass container. All controls proved negative for herbicides when analyzed by gas chromatography.

Post-application samples were taken from an 18-inch square of soil not protected by vegetation. A soil mix was transferred to a glass container from the top inch of soil and from the six to nine-inch levels (except for the initial collection when the deeper sampling was omitted). This was done once along a line at a right angle to the centerline of sprayer movement at distances of five, ten and 15 feet at two locations set approximately 100 feet apart. Thus the test lines in 1978 were replicated twice and the soil samples twice for the first sampling and four times for the second and third. In 1979 the samples were a mix of soil dug from the surface to the eight-inch level at locations five, ten and 15 feet from center line along a single, right-angle line. As there were no replications, the area from which the soil mix was collected was increased from 18-square inches to 36-square inches. The glass containers were one or two-pint amber, screw-top, xylene washed, wide-mouth laboratory jars. Soil samples were frozen within three hours of collection and shipped frozen to the Department of Environmental Conservation's Juneau laboratory for processing or transshipment to an EPA-approved commercial laboratory (Morse Laboratories, Sacramento, California). Department sample custody procedures were observed throughout the study.

The first TORDON 101 application was made at Mile 162 of the railroad right-of-way on June 9, 1978 and was sampled at two hours, 14 days and 75 days. On July 18, 1978 an application was made by Division of Highways' personnel at Fairbanks International Airport. Soil samples were collected at two hours, 23 days and 51 days. A third plot was established at Anchorage International Airport Autust 1, 1978 in cooperation with staff of the southcentral region of the Division of Highways. Soil samples were collected at two hours, 16 days and 43 days. For all applications of TORDON 101 the concentrate was mixed at a rate of one gallon in 99 gallons of water. All three spray units were rigged with piston pumps powering boom and nozzle attachments, but for the tests the herbicide was applied through hand-held pressure hoses used for spot spraying.

In addition to the plots described above, applications were made to selected areas of heavy brush on Anchorage International Airport with picloram pellets and sprays, AmmateX and KRENITE(R), to measure efficacy in Alaskan conditions of these non-phenoxy compounds. None were judged to be fully effective substitutes for the TORDON 101 picloram/2,4-D mix.

In 1979 it was decided to concentrate our efforts on a single plot and sample it for soil residues in a manner amenable to graphic representation. A plot was applied in cooperation with the Alaska Railroad on a section of right-of-way near the village of Eklutna, 30 miles north of Anchorage. The swath was 26 by 200 feet and the soil samples were collected and processed as described above. In 1979, single, one-year samples were collected from the Anchorage and Fairbanks airport plots.

In 1981 label recommended dosages of the GARLON 4 formulations (DOW USA) were applied to selected plots along one side of the railroad right-of-way using a spray truck adapted to run on either road or rail. A three-nozzle manifold applied the mix at a recommended rate of 100 gallons per acre on a series of plots sprayed June 4, 1981. In July 1981 an additional plot of the same width, application rate and dose was applied using a single hand-held nozzle. Each plot extended a distance of 25 feet one side of the track centerline; a measurment confirmed by vegetation "brown-out." The June plots were applied north and south of the town of Wasilla (about 60 miles north of Anchorage) and designated, from south to north: RR81B3, RR81B4 and RR81B5. From each plot soil samples were taken from a mix dug between one and eight inches at stations ten and 15 feet from centerline. Samples were placed into xylene-washed, brown glass jars and frozen at -15 degrees Farenheit as soon as possible. The June applications were sampled eight times (plots RR81B3 and RR81B4) or seven times (RR81B5) at irregular intervals between two hours and 42 days after spraying. All controls were negative for the pesticide.

As the month of July 1981 was unusually rainy (NOAA 1983) in southcentral Alaska, a second triclopyr plot was established near the village of Eklutna on July 27, 1981. The herbicide was applied over a 20-foot swath (as measured by plant kill) to one side of the track centerline. The application rate was the same as used in June. Soil samples were taken, in the manner described above, nine times at irregular intervals from two hours after spraying to day 67. The plots were observed daily until "brownout" was judged to be complete and then viewed by one or the other of the authors at weekly intervals until freeze-up. Their judgements were subjective and attempts to distinguish between control of the variety of Alaskan willows--the major problem brush species in southcentral Alaska was unsuccessful.

To evaluate the effectiveness of triclopyr in Alaska's interior areas, a plot was sprayed at Nenana (forty miles west and south of Fairbanks) and observed, during the growing season, at monthly intervals until October 1983. The mean triclopyr residues of three soil samples taken after two years were: 0.01 ppm, 0.09 ppm and less than the limit of detection (0.01 ppm) The range of the recoveries was from less than 0.01 ppm to 0.10 parts per million.

All triclopyr soil samples were processed and analyzed by gas chromatography for the three components of the formulation: triclopyr methyl ester, 3,5,6-Tricloro-2-pyridinol methyl derivative and 2,Methoxy-3,5,6-tricloro pyridine. As the triclopyr residues were consistantly higher, only this compound was plotted in Figures 1 and 3.

RESULTS

Corrected for swath width and rig speed, the dosages applied to the three 1978 TORDON101 plots are shown in Table 1. These dosages are within the range recommended for brush control with 2,4-D (1/4 to 4.0 pounds of active ingredient per acre) and for picloram (1/4 to 8.0 pounds per acre). Table 2 lists the detectable mean recoveries of the 2,4-D and picloram from eighty-three 1978 soil samples, recorded in parts per million (ppm) and sampled at time intervals of approximately 24 hrs, two weeks and six weeks. At two and six weeks the samples were divided into high and low (one inch vs. six to eight inch) samplings.

The 1979 TORDON 101 soils were taken across the swath five, ten and 15 feet from the center line of sprayer travel and were a mix dug from a 1-inch to 8-inch level. The three samples were not replicated. The first soils were taken 1/2 hour after spraying and thereafter at intervals of 24 hours, 48 hours, three days, four days, five days, six days, 17 days and 30 days. These were frozen, shipped and analyzed as were the 1978 soils: Figure 2.

Figure 1 illustrates that triclopyr degradation on two Wasilla plots sprayed in 1981 was similar and that detectable residues were present 42 days after spraying. Figure 2 illustrates the residue levels of 2,4-D from soil samples collected in 1979. The level of detectability for the 2,4-D was lower than for triclopyr: 0.005 ppm vs. 0.02 ppm. However, no phenoxy residue was detected after the third day while triclopyr residues were found even at day 42.

Soil temperatures recorded in Palmer, Alaska in 1981 (University of Alaska 1981) between June 1st and August 10th indicate a mean temperature of 54.8 degrees Farenheit (F) in fallow land and 51.4 F in grass. The range was 50 to 58 degrees F (fallow) and 40 to 57 degrees F (grass). The time of the readings was 8 a.m., however the sun at this time of year had been above the horizon for four to five hours. The data during the most active growing weeks indicates no large variation in soil temperatures. In addition, there is little difference in soil temperatures between the relatively dry month of June 1981 (0.095 inches of rainfall) and the wet July southcentral Alaska experienced in 1981: 4.39 inches of rainfall. The consistancy of the soil temperature readings suggests that there may be other factors, such as rainfall, rather than Alaska's comparatively stable summer soil and air temperatures, that affect the disappearance of the pesticides evaluated.

No detailed analysis of brush kill and species specificity were made during the course of this study; however the authors have been concerned with vegetation management along the right-of-way of the Alaska Railroad since 1976 and it is their opinion that triclopyr was as effective as 2,4-D against most problem species of brush encountered.

When 2,4-D is mixed with picloram, as in the TORDON 101 formulation, visible injury to brush occurs several days sooner than when triclopyr is applied but by day ten after application there is little difference between the two formulations. At the end of summer, control on the 1981 plots was judged to be equal to that achieved in 1979 when the 2,4-D/picloram mix was applied.

One exception to the almost equal effectiveness of triclopyr and TORDON 101 was that the latter compound killed black spruce up to four-inch trunk diameter while the same sized trees often survived an application of triclopyr. This could be an advantage for the newer herbicide as spruce is not a major infringer upon the railroad right-of-way and marketable stands of both black spruce (Picea mariana) and white (Picea glauca) spruce border Alaska's rights-of-way in many areas.

Disregarding the low 24-hour reading from the 1981 plot RR81B4, the residues recorded from plots located north and south of Wasilla are much the same: Figure 1. A triclopyr residue exceeding 0.1 ppm was recovered on day 42 at both locations. This was in mid-July 1981 after over a month of warm, clear weather with almost no precipitation until the Fifth of July. Samples taken from the 1981 Eklutna plot, sampled for triclopyr 15 feet from centerline, demonstrate nearly the same recovery levels after one month; Figure 3. This is true even though the area sprayed in Eklutna was soaked by almost daily rains during July and August.

It is of interest that the 1979 picloram/2,4-D application was subjected to the same wet, cool summer weather conditions as were the 1981 Eklutna samples. The question whether the 2,4-D degraded in less than a week or moved from the plot in the abundant surface and ground water must remain a major unanswered problem defined in this series of investigations.

CONCLUSIONS

From samples taken on day 51 in Fairbanks in 1978, the mean recovery of 2,4-D was 0.111 ppm at one inch and 0.333 ppm between a soil depth of six and eight inches. In Anchorage, residues were (after 43 days) 0.558 ppm at one inch and 0.079 ppm between six and eight inches. There was, however, no detectable residue in the railroad plot after two hours. Picloram residues at the end of the 1978 season were: Anchorage 0.005 ppm (one-inch soil level) and 0.010 ppm (eight-inch level); Fairbanks, 0.043 ppm (one-inch level) and 0.031 ppm (eight-inch level). One year samples taken in July 1979 showed a picloram residue of 0.020 ppm from the Anchorage plot and none from the Fairbanks plot There were no detectable 1979 2,4-D residues from either plot.

From our 1978-1979 data it must be concluded that there was a small but detectable residue of the 2,4-D and picloram components of TORDON 101 present in the plots at the end of the short Alaskan summer and picloram residues persisted into a second year.

While it was gratifying to learn that there was no build-up of the phenoxy compound from the 1978 applications, the authors, in view of the measurable 2,4-D residue found at the end of the growing season, established a 1979 TORDON 101 test plot near the village of Eklutna and sampled at more frequent intervals. Mix, speed, pressure and applicating techniques duplicated, as nearly as possible, those used on the 1978 plots. Picloram residues detected from the 1979 soil samples indicate there is a measurable residue of slightly less than 1/2 part per million present at day 18 and a mean recovery from the 30-day samples of 0.1 ppm. There were no detectable residues of 2,4-D after two days. The mean residues of the 2,4-D samples taken across the swath were: 1/2 hour, 0.033 ppm; 24 hours,0.60 ppm; and 48 hours, 0.03 ppm.

Our efforts to determine the relative extent to which the two components of TORDON 101 migrate through the soil must be judged unsuccessful as cost factors precluded taking soil samples from the surface to the eight-inch level in 1979; however in our analysis in 1978 only picloram showed a higher concentration at eight inches than at the one-inch level: 0.01 ppm as compared with 0.005 ppm after 43 days in the Anchorage Airport plot.

Our data from the 1981 studies indicates that the degradation curves of two of the three species of the GARLON formulation, triclopyr and pyridinol, closely follow each other while the Methoxy pyridine component was as near or below the level of detectability. Should triclopyr be adopted as the brush control agent of choice in Alaska, a routine monitoring program might save time and money by analyzing only for the presence of triclopyr.

On Figure 1. the residues recovered from plots located north and south of Wasilla are much the same. A triclopyr residue exceeding 0.1 ppm was recovered on day 42 at both locations. This was mid July and the plots had the benefit of over a month of clear, warm weather with almost no precipitation until the Fifth of July; Figure 3. Residues from the Eklutna plot sampled 15 feet from centerline demonstrate nearly the same recovery levels after one month as do the Wasilla samples. This was true even though the area sprayed in Eklutna was soaked by almost daily rains throughout its lifetime. The 1979 picloram/2,4-D application was subjected to the same wet, cool summer weather conditions as were the 1981 Eklutna samples: July 1979 3.84 inches and July 1981 4.39 inches of rainfall. (NOAA 1983). The question whether the 2,4-D degraded in less than a week or moved from the plot in that summer's abundant surface and ground water remains a major unanswered area resulting from this series of investigations. The authors feel, however, that on the basis of this data they must advise their organizations that the fate of much of a 2,4-D/picloram residue in the soil is unknown while triclopyr may be judged to remain within the swath even though it is the more persistant herbicide.

DISCUSSION

Although it is now more than a decade since the end of the Viet Nam War, the phenoxy herbicides may be forever associated with "Agents" Orange, Blue and White used in that conflict. This is especially true in Alaska, the forty-ninth state, whose young population remembers that war as the major event of their coming to maturity.

Our 1978 data suggested that only a small phenoxy residue remains in the soil at the end of Alaska's short summer and that none is present after one year; however 20 days after the 1978 applications picloram soil residues exceeded 0.003 ppm in all samples and for the herbicide of major concern, 2,4-D, there was also a substantial 1978 soil residue on day 43 in Anchorage (mean recovery of 0.319 ppm) and in Fairbanks (mean recovery 0.072 ppm). This appeared to be contradicted by our 1979 data when our Eklutna plots revealed no 2,4-D residues after two days and a picloram soil residue below the limits of detectability on day 30.

The authors suggest two possibilities: either one or both compounds were (a) transported in surface and ground water out of the sampling area, or (b) degradation occurs at a more rapid rate in years of above average rainfall.

The 1981 data presented and the detection of two-year triclopyr residues from Nenana indicate that this product is as persistant in the environment as is picloram and may be far more so than 2,4-D. Why then do both authors suggest the more recent herbicide can be a viable substitute for the proven TORDON 101 picloram/2,4-D mix?

Operationally, triclopyr can be an acceptable substitute for the phenoxy herbicides when controlling native species of brush along a right-of-way that extends from a latitude of less than 60 degrees north to within 100 miles of the Arctic Circle. Picloram is added to 2,4-D in the TORDON 101 formulation to speed plant kill, but an evaluation of our 1981 Eklutna plot demonstrates that triclopyr, even when applied to plants that are mature, will result in acceptable brush control. In July 1983 the authors evaluated the dense Wasilla Hill plots sprayed with triclopyr in 1981, and agreed that woody-plant herbicides would not be needed for at least another two years. It is possible, too, that a planting of native grasses might extend this four-year period indefinitely.

Although triclopyr is more persistant in our environment than 2,4-D, the fact that it stays within the right-of-way can be an advantage when planning and monitoring a modern vegetation management program. Picloram, evaluated in 1979, also degrades slowly but, in addition, is notorious for migrating in ground water from the point of application.

Triclopyr, with a molecular construction incapable of producing dioxins during the manufacturing process, may offer a substitute for the phenoxys that would be acceptable to both those who must maintain Alaska' rail and road rights-of-way in a labor-intensive economy and, on the other hand, a public concerned with the long-term effects of chemicals introduced into an unspoiled, sub-arctic environment.

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ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the help given this study by the Commissioners and staffs of the Alaska Departments of Environmental Conservation and Transportation, and the General Manager and Chief Engineer of the Alaska Railroad. Pesticide and technical help were supplied by Dow Chemical USA.

Table 1

1978 TORDON 101 Application Rates

	Fairbanks 10 ft. swath	Anchorage 20 ft. swath	Mile 162 20 ft. swath
2,4-D	1.55 lb/A ai[1]	1.70 lb/A ai	1.55 lb/A ai
picloram	0.395 lb/A ai	0.433 lb/A ai	0.395 lb/A ai

1. pounds per acre active ingredient

Table 2: Mean recoveries of herbicide in parts per million (ppm) from soils taken in 1978 in Anchorage, Fairbanks and on the Alaska Railroad.

	2,4-D			picloram		
Plot location	Time	Mean recovery high	Mean recovery low	Time	Mean recovery high	Mean recovery low
FAI[1]	2 hours	3.98	---	2 hours	0.972	---
	23 days	0.254	0.062	23 days	0.230	0.050
	51 days	0.111	0.033	51 days	0.043	0.031
ANC[2]	24 hours	0.874	---	24 hours	0.224	---
	15 days	6.48	0.313	15 days	0.362	0.004
	43 days	0.558	0.079	43 days	0.005	0.010
RR[3]	2 hours	0.870	---	2 hours	0.056	---
	14 days	ND*	ND	14 days	ND	ND
	74 days	ND	ND	74 days	ND	ND

1. FAI: Fairbanks International Airport
2. ANC: Anchorage International Airport
3. RR: The Alaska Railroad, mile 162

* ND: No detectable residue.

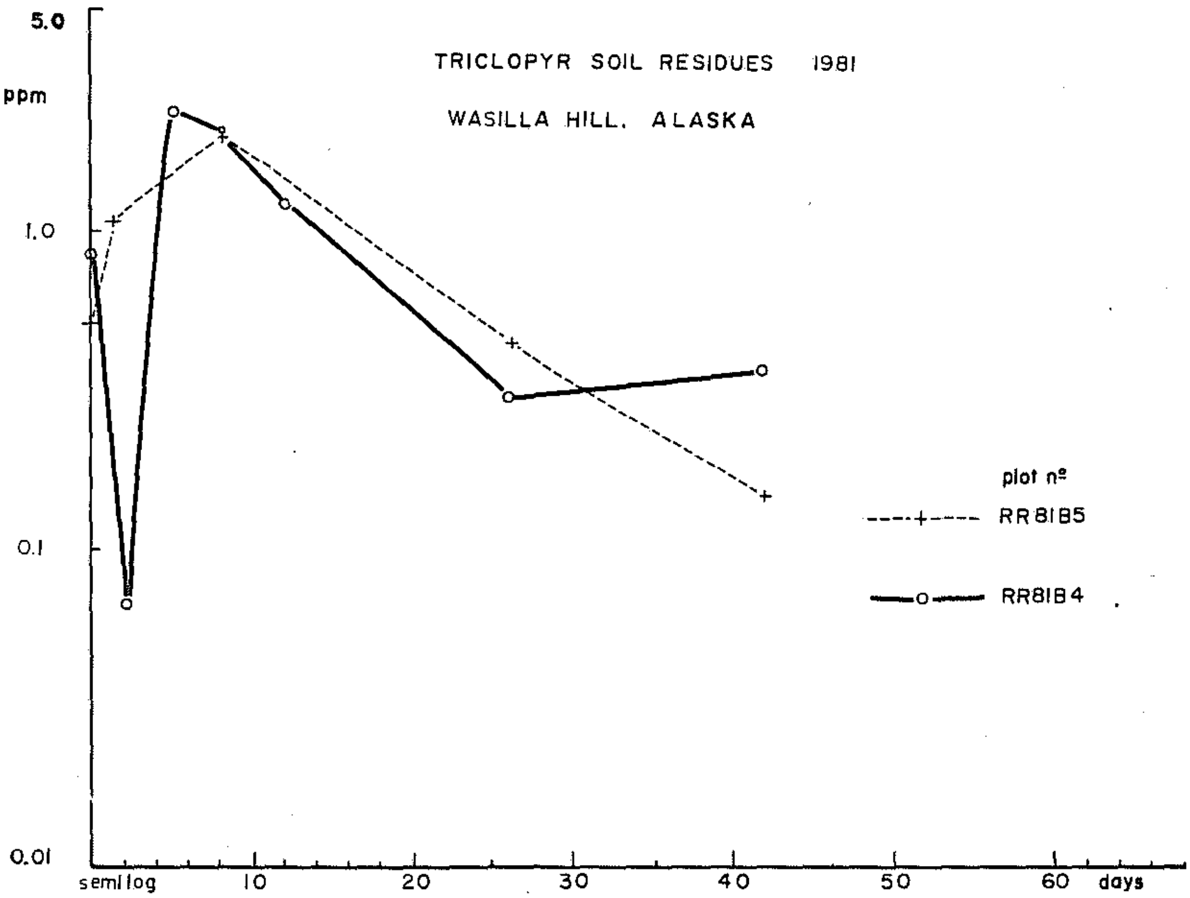

Figure 1. A gas chromatograph analysis of soil residues of triclopyr recovered from a GARLON 4(R) application made near Wasilla, Alaska on June 4, 1981. Both plots were on one side of the right-of-way of the Alaska Railroad and separated by a distance of approximately seven miles.

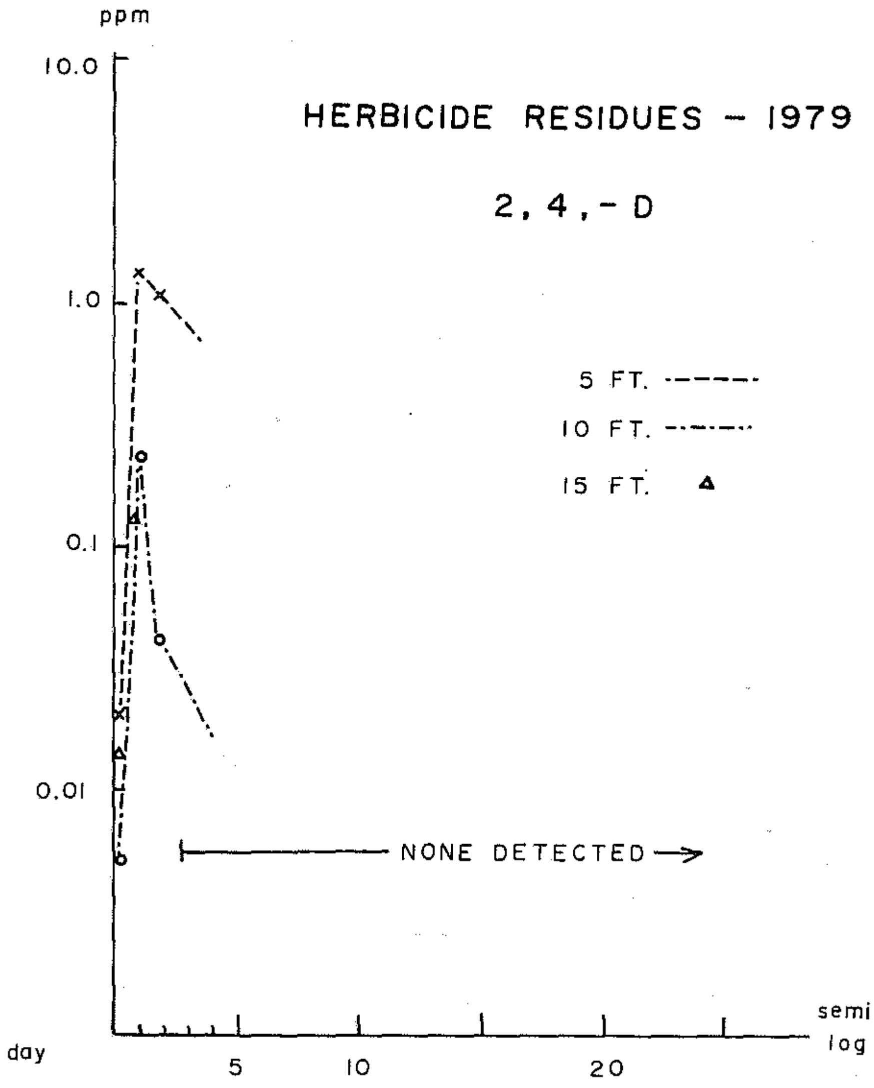

Figure 2, 2,4-D residues in parts per million measured from 30 day soil samples dug on our 1979 Eklutna test plot.

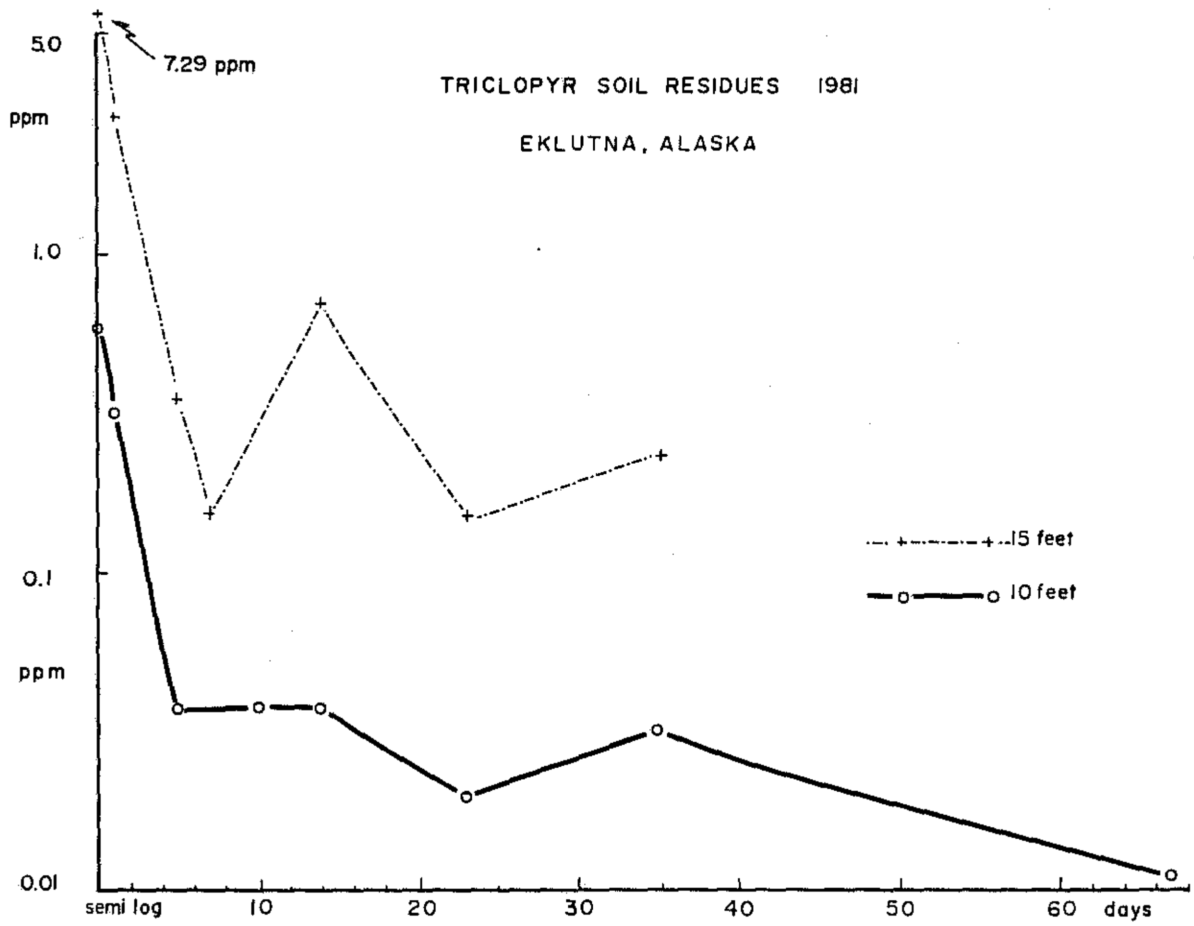

Figure 3. Soil residues of triclopyr recovered at a distance of ten and fifteen feet one side of the centerline of the Alaska Railroad track after a GARLON 4(R) application made July 27, 1981. Measured by gas chromatography.

EFFECTS OF ONSITE WASTEWATER DISPOSAL ON GROUNDWATER

by Bob Wemple

ABSTRACT

The use of onsite wastewater disposal is the most common method of treatment for domestic waste in nonpermafrost areas of Alaska. In this paper recent literature is reviewed on the fate of infectious organisms and nutrients in the soil and groundwater. Methods of onsite wastewater disposal used in Alaska are reviewed and cold climate design considerations are discussed. Application rates, site limitations, and design modifications are described.

INTRODUCTION

In September,1984 the City of Anchorage announced that it would begin a 50 to 65 thousand dollar study to determine the extent of groundwater pollution from the 35,000 onsite wastewater disposal systems in the area (Grilly,G.E., 1984). Pollution of groundwater from onsite disposal systems has also been a problem in Fairbanks (Nelson,G.L.,1978). Generally only the shallow groundwater table has been affected. Outside urban areas of Alaska, the groundwater quality is generally excellent. This is attributed to the sparce population compared to the relatively vast land area (Hammond J.S.,Mueller,E.W.,1977). If future development is to occur without pollution of groundwater, rational decisions must be made as to where onsite systems can be used, what effluent application rates should be and how far systems should be separated from surface or drinking water. The difficulty in determining design criteria for onsite systems is reflected in the wide range of state regulation standards listed in Table 1 (Dreissl,J.1983.) (Alaska,1983.). This paper reviews what has been presented in the literature concerning the fate of pollutants and discusses the implications of this research on the design of systems in Alaska.

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TABLE 1 Variability of State Codes (with Alaska)

Criteria	Range	Alaska
Setbacks,Wells	11-92m(35-300ft.)	100ft.
Trench Spacing	1.8-3m(6-10ft.)	-
Min. Perc Rate	yes-no	no
Max. Perc Rate	30-120 min/in	60min/in
Trench Width	0.3-0.9m(12-36in)	-
Sizing	Soils-Perc Rate	Soils-Perc Rate

PROCESS

Raw Wastewater Flows. In order to understand the design of soil absorption systems it is improtant to look at the entire treatment process. Generalities concerning the design of the leachfield may not apply if other processes in the system are unique. For example raw wastewater flow and quality may vary considerably. Flows from households in Alaska have been found to be similar to those found elsewhre, but there are exceptions (Alter,A. 1969). Many houses are occupied only in the summer and lodges and hotels may show a dramatic change in flow over a season depending on the number of guests. Another situation found in Alaska is homes that have to haul water and have much more concentrated wastewater flows. These conditions must be taken into consideration when the soil absorption system is designed.

Septic Tank. Septic Tank design is too broad a subject to discuss in detail in this paper, however a general description of the septic tank treatment process is important in understanding the design of the soil absorption sytem. Basically the wastewater passes through anaerobic biological treatment with a retention time of about 2.5 to 5 days. The most important aspect is the removal of inorganic solids and the conversion of organic soilids into dissolved organic forms. The lack of regularly maintaining septic tanks by pumping out accumulated solids is a major factor in septic system failures (Quadra,1982).

Soil Absorption System. Leachfields are the most common type of soil absorption systems used in the United States outside Alaska. In Alaska a deep trench or seepage pit is more common(Quadra,1982). Regardless of the method of application, some general characteristics apply to the interaction of the effluent with the soil. In the first several inches around the trench, a slime layer forms due to the storage of slime capsules by bacteria when in an environment of excess carbonaceous nutrients. The slime layer or clogging zone is the boundary between the saturated, anaerobic and the unsaturated, aerobic areas of the soil (sometimes there are layers of aerobic and anaerobic conditions mixed). Pollutants are removed by adsorption onto soil particles, biological conversion into other forms, chemical precipitation, dilution in groundwater or combinations of these processes.

FATE OF POLLUTANTS

Infectious Organisms

Bacteria, viruses and parasites are the three general types of waterborn infectious organisms. Eighty disease ourbreaks in noncommunity groundwater systems were reported to the Center for Disease Control and the EPA from 1971 to 1979 (Wilson,R.1983). This is an average of about 6 out of every 10,000 systems. The rate of outbreaks is lower for groundwater sources than surface water sources supporting the general trend of regulation of water supply. Many more cases of contamination probably go undetected. Most of the disease outbreaks are related to virus infection (Gerba,1983).

Some members of all three types of organisms have infective doses of less than ten detectable units. However, enteric bacteria have a wide range of required dose to produce a responce; up to 10-5 to 10-8 cells to produce a 50% attack rate (Akin,E.W.,1983). Each type of infectious organism has different fates in soil and groundwater.

Bacteria. Most studies on the pollution of groundwater by infectious organisms have measured bacteria because standard tests were developed to measure indicator bacteria that were similar to pathogenic forms. All but one of the reported disease outbreaks from 1971 to 1979 showed increased amounts of fecal coliform bacteria in the water source(Wilson,R.1983). Tests are complicated by the fact that fecal and other indicator groups of bacteria are found naturally in the soil. One technique developed recently uses antibiotic resistent bacteria that can be differentiated from naturally occuring strains (Rahe,T.M.et.al.,1978). Surface water usually has a low concentration of naturally occuring fecal coliform, however deep groundwater usually has none.

The most important factor in bacteria removal is the presence of an unsaturated zone in the system. Studies show concentrations of several million per 100mls. are reduced to acceptable levels in the first 2-3 feet of soil under normal conditions (Tyler,E.J. et.al.,1977) (Brown et.al.1977) (Hagedorn,1983). Laboratory studies demonstrate the importance of a clogging zone especially in sandy soils (Ziebell et.al.1975.)

Mechanisms for bacterial removal include physical straining, absorption onto soil particles and die off from attrition. Physical straining in the clogging zone is usually the most important (Gerba, C.P.et.al.,1975). Absorption onto soil particles is more significant in soils with a higher clay content (Gerba,C.P.et.al.,1975).

Studies indicate that the lifetime of bacteria in soil is about two or three months (Weaver,1983)(Gerba,C.P.et.al.,1975). Generally, lifetime has been determined to increase at lower temperatures (Lance,J.C.,1983)(Gerba,C.P.et.al.1975). In arctic conditions bacteria may even survive for a few years (Johnson,R.A.1977). Gordon (1972) showed that 2.1-4.2% of fecal coliform added to the Tanana River, Alaska remained after seven days. Weaver found the lifetime under laboratory conditions was longer at 5 C than at 22 C in some soils and shorter in others. Obviously, other factors are important to survival. Lifetime has generally been found to increase with increasing moisture content,moisture holding capasity, organic content and pH of the soil (Gerba,C.P.et.al.,1975).

Persistance of bacteria in groundwater have been measured in studies of systems where groundwater was in direct contact with leachfield lines. Results vary according to peticular conditions at each site. Stewart and Reneau (1983) studied fecal coliform movement through coastal plain soils that had fluctuating high water tables. Coliform concentrations over 1000/100ml. were measured 12m from the drainfields in some cases. Movement was reduced significantly when unsaturated conditions prevailed.

Movement of antibiotic resistent bacteria were monitered through saturated soils in Oregon by Rahe et.al.(1978) and Hagedorn et.al.(1978). Rahe concluded that movement was by partial displacement through macropores in the soil. The bacteria survived up to 96hrs. and moved at a rate up to 15cm/hr. Hagedorn found survival rates of at least 32 days and found positive samples 15m from the souruce.

Peavy and Groves (1977) studied a system in Boseman Montana on an alluvial fan where the groundwater table was 1.2m deep. Fecal coliform counts were very erratic and positive samples for more than 50% of the samples were found only at a point directly under the drainfield.

DeWalle and Schaff (1980) studied 389 water quality records from 98 wells in a 169 square mile drainage area in Washington. Average fecal coliform counts in the 31 ft. aquifer were 8/100ml.,at 228 ft. there were 6/100ml. and at 503 ft.the average was 4/100ml. An estimated 100,000 persons were on unsewered systems and the estimated flow from the septic tank leachfield systems was 9mgd. (see also <u>Nitrogen</u>.). Positive samples occured between October and May during rainfall. Median coliform counts from surface samples increased from an average of 64/100ml. in

1962 to 1200/100ml. in 1973. Sources other than onsite wastewater disposal systems can contribute to pollution of surface water.

Viruses. Of 550 reported cases of waterborn disease from 1946-1977, 65% had viral origin (Gerba,1983). Unlike bacteria,however, pathogenic viruses are found in wastewater from infected households only and until recently no standard method existed to isolate viruses. Poliovirus and coliphage are the most commonly studied in recent years, however the two types may differ significantly in their fate in soils (Gerba,C.P.et.al.,1975). The clogging zone of onsite systems is effective in removing viruses as well as bacteria. Brown et.al.(1977) studied disposal fields in three types of soils in Texas and found that coliphage and fecal coliform were removed through approximately 1m of any soils tested.

Due to their small size, adsorption usually plays a more significant role in removing viruses than physical straining (Loehr et al.,1979). Survival of viruses is enhanced by lower temperatures. Viruses have been found to persist about 3 or 4 months at 4^{0}C (Lance,J.C., 1983.) (Kreissl,J. 1983). Limited investigation shows that viruses can travel significant distances in groundwater (45.7 meters) but information in this area is limited (Vaughn et.al.,1983; Gerba,1983).

Parasites. Parasites are not considered a great risk to groundwater pollution from onsite disposal (D'Alessio,D.J.et.al., 1983). All reported cases of outbreaks from 1971-1979 for Giardia lamblia were exclusively associated with surface or shallow groundwater sources (Wilson,R. 1983). Parasites are generally not considered a great risk because of their size (10-20 um). In soils that form structural cracks, this may be an exception (D'Alessio,D.J. et.al., 1983).

Nutrients

Nitrogen and phosphorus are a concern for groundwater contamination for both public health and environmental reasons. Nitrate nitrogen is the usual end product of nitrogen in wastewater and concentrations over 10 mg/l NO3 N are considered dangerous to breast feeding infants(EPA,1976). Nitrates can be reduced to nitrite in the gastrointestinal tract and will react with hemoglobin and impair oxygen transport. This can be hazzardous to infants under 3 months of age (EPA,1976). Concentrations of unionized ammonia over 0.02mg/l NH4 N are considered harmful to freshwater fish (EPA, 1976). The portion of ammonia in the unionized form is highly dependent on pH and temperature. Stimulaton of eutrophication in lakes is usually limited by phosphate phosphorus, however the concentration of nitrogen also can have a significant effect(Smith,V.H.,1982).

Most uncontaminated Lakes have concentrations of phosphate of about 0.03 mg/l P or less (EPA,1976).

Nitrogen. Most nitrogen (about 75%) applied to the soil from septic tank effluent is in the form of ammonia(EPA,1980). In addition, organic nitrogen which accounts for the remaining 25%, can biodegrade into ammonia and other products. As the ammonia first contacts the soil it may be adsorbed onto soil particles through the cation exchange process. The process is reversible and in the aerobic environment of the soil ammonia is converted to nitrite and nitrate by nitrifying bacteria. Conditions favorable to removal of other pollutants in effluent (unsaturated aerobic zones) are also favorable to conversion of ammonia to nitrate. Dilution of the groundwater is then the mechanism of removal for nitrate. Some nitrogen may be removed if anaerobic conditions are found in a layer following nitrification. In the presence of carbonaceous material, denitrifying bacteria can convert the nitrogen to gas.

A study of the fates of pollutants in a field in Boseman Montana found nitrate concentrations to be in excess of 45mg/l NO3 N in samples of groundwater 9m from the field. The groundwater depth was 1.2m. An unusual groundwater flow pattern was felt to be the reason for the high reading. In the same study, conversion to nitrate was essentially complete before the groundwater was reached. Other studies have shown that ammonia is converted to nitrate in the first few feet of the soil (Tyler,E.J.,1977). A sampling of fourty onsite disposal systems in Maine showed high concentrations of nitrate under and beside the beds, however no noticeable increase in natural concentrations were observed from tests 15.36 and 30.72 meters downslope from the beds (Struchtemeyer,R.A.,1983). A study was conducted in Connecticut in a residential area with a density of one house per acre (Luce,H.D. and Welling,T.G.,1983). The highest nitrate concentration found in the groundwater was 23.4 mg/l N in a 1.6m well 0.5m from the edge of a field. Substantial transport beyond 0.5m was not found at any of the five individual systems monitered.

DeWalle and Schaff (1980) studied samples from wells in a drainage in Washington(see also Bacteria.) and found a slight increase in the averages of nitrate concentrations from 98 wells (210-1064ft. deep) over a thirty year period. Average levels ranged from about 1-4mg/l. Correlations were noted between higher nitrate levels and both shallower wells and occurance of precipitation. Calcium increased 60% over the same period from 8-13mg/l. A high degree of degradation was apparent because ammonia was usually not detected.

Phosphorus. Septic tank effluent usually contains predominantly orthophosphate phosphorus. This ion is usually chemisorbed onto mineral particles in the soil and precipitates.

Accumulation of phosphorus may occur over time in some unusual sandy soils (Tyler,E.J.et.al.,1977). In the study of fourty sites in Maine, the means of the PO4-P tests were all less than 1 mg/l even those directly under the beds (Struchtemeyer,R.A.& Black,R.W.,1977). Similar low measurments were found in the groundwater studies in Connecticut(Luce,H.D.and Welling,T.G.,1983). Gilliom and Patmont(1983) studied lake phosphorus loading from septic systems by seasonally perched groundwater in Pine Lake Washington. All samples were less than lmg/l PO4-P and less than 1% of the effluent phosphorus loading was estimated to reach the lake.

DESIGN OF SOIL ABSORPTION SYSTEMS

Design Objectives

System Failure. There are many reasons a field may fail, but the end result is the same, the effluent backs up onto the ground or out of the septic tank or distribution box. Some experts have contended that all systems will eventually fail (become "blinded"), however some studies indicate that this does not necessarily have to be the case if the design is good to begin with (Anderson,J.L.et.al,1983). Another result of improper design, which is not as easily detected, is pollution of groundwater. In Alaska systems must also be protected from freezing.

Limiting Conditions. The first step in the design process is determining if a site can be used for a soil absorption system. If there is permafrost, bedrock, impermeable clay layers, or groundwater closer than 6-10 feet of the surface, onsite disposal may not be an option. In southeast Alaska, activated sludge package plants with direct discharge are often used because of shallow bedrock (Quadra,1982). Fractured bedrock is also considered a limiting factor due to potential groundwater contamination. This condition is often associated with limestone and sandstones with well developed joint patterns.

Short Circuiting. Some fine textured soils develop structural cracks that can cause short circuiting of the effluent to the groundwater. This characteristic should be detected through observation of the soil horizon in excavation and in percolation tests. Hydraulic conductivity in these soils would vary drastically from that predicted on the baises of soil texture. Short circuiting can also occur around rocks in the soil and if the fraction by weight of rocks greater than 3in. in diameter exceeds 25-50% by weight , it is considered a limiting condition (EPA,1980).

Groundwater Flow. Measurement of groundwater flow is an important consideration in the site orientation of an onsite system, however groundwater flow is not used to determine separation distances from wastewater systems to potable groundwater systems. One hundred feet is the minimum separation distance between subsurface drinking water sources and disposal systems (Alaska,1983). Groundwater velocities are generally very small; from a few inches a day to a few feet per year (Pettyjohn,W., 1983). The occurance and distribution of groundwater in Alaska is variable however many areas have seasonally high levels (Johnson,R. 1978). The most productive areas for ground water are in the valleys of the major rivers (Feulner,1972). High groundwater tables are also found in areas of Anchorage and Fairbanks (Sullivan,G.M., 1979) (Nelson,G. 1978). Flow of groundwater is predicted by Darcy's Law - $Q=KA(a-b)/L$ where Q is the flow rate,K is a coefficient of permeability,A is the cross sectional flow area, (a-b) is the change in head and L is distance (Fielding,M.B. 1983). In Fairbanks, the theoretical time for pollutants to travel 100ft. varies from 8,000 years for a silty sand to 3 days for a medium gravel (Nelson,G.1978).

Application Rate

Standard Percolation Test. This onsite measurement of soil suitability was developed in 1957 by the Public Health Service and is still the standard for design. However, studies have shown that the test may be as much as 90% off in the same area (EPA,1980). The way the hole is dug is very critical in some soils and in clayey soils the area around the test hole must be saturated to allow the clay particles to swell. The test does not replicate real conditions in a trench because there is no formation of a clogging layer. This is especially noticeable in sandy soils where the clogging layer may change the infiltration rate by as much as 100% (Tyler,et.al. 1977). Even though hydraulic conductivity is not directly related to acceptable long term application rates, sandy soils generally have higher acceptable application rates than soils with lower hydraulic conductivities (Anderson,et.al. 1983). The test measures the saturated flow conditions of the soil and it has been stated that following formation of the clogging layer, the flow is through an unsaturated soil zone. The larger pores in the soil are filled with air when the soil is unsaturated and movement of water becomes more dependent on capilary action in the smaller pores, so hydraulic conductivity slows down. Measurements of saturated hydraulic conductivity must be related to unsaturated conditions by emperical data. Application rates for various soil classification types and percolation rates are listed in the State of Alaska Wastewater Disposal Regulations (Department of Environmental Conservation, 1983).

Permeability. The largest source of information on soils is provided by the Soil Concervation Service in their reports. Permeability is rated for various soil types and is given in inches/minute. The use of this data cannot exclude on site evaluations because SCS informaton is accurate to only about 500ft. The soil classification developed by the SCS for particle size gradation has been used as a general guide for determining site suitability however it is not considered sufficient for design (Hantzsche,W.T.et.al.,1983). Field and lab tests for hydraulic conductivity can be done and they are more accurate in predicting the long term acceptance rate, however they are time consuming and very site specific. (Anderson et. al. 1977). Particle size distribution or texture is only one of many soil characteristics that determine soil permeability. Bulk density, coarse fragment content, clay minerology, organic matter content, structure and soil chemistry are also important (Hantzsche,W.T. et.al., 1983).

Dosing. The significance of the clogging layer on removal of pollutants has been discussed,but little data exists on pollution of groundwater from the start up of new systems. In a standard trench the hydraulic loading increases near the distribution box and a zone of overloading proceeds across the trench. Some estimates of the time to reach equilibrium are six months (Kreissl,J. 1983). This is an important consideration in designs incorporating alternating fields. Dosing is most often associated with pressure distribution systems, however it can be achieved in gravity systems with dosing siphons. Effluent application statagies were studied by D.L. Hargett et.al.(1983) in a silty clay loam soil and the results indicated that dosing has little if any long term advantage. Results may be different under different soil conditions. Considering the importance of the clogging layer in sandy soils, it would seem prudent to avoid this design method if the groundwater table and permiability of the soil are high.

Curtain Drains. One method used to install leachfields in areas with high ground water tables is to place perforated pipe around the system, draining away from the field to reduce the water table level under the leachfield lateral lines. Reneau (1978) studied this kind of system in Virginia and found that the drain tiles prevented failure, but densities of coliform bacteria in the groundwater were difficult to access. Levels of 10 to 1000/100ml. were found 1.5m from the drain tile and levels in the outfall were <200/100ml. Wilson et.al.(1982) also studied drained soils absorption systems. Nitrate levels 1.8 deep and 6m back were 0.6 to4.1mg/l N and fecal coliform were <500/100ml.

Onsite Disposal Systems

Mound Systems. When a site has a shallow depth to bedrock or a high groundwater table, excess fill may be used to build the soil absorption system above the existing ground. As long as the fill material promotes a zone of unsaturated flow, removal efficiencies are comparable to standard systems (Engle,C.R., Hermanson,R.E.,1983).

Seepage Pits. This is a common type of soil absorption system used in Alaska (Johnson,R.A., 1978). It is an attractive alternative to the conventional leachfield system because wastewater heat is conserved and the system is more easily protected from freezing. The design of the soil contact area for the application rate is based on the sidewall area rather than the bottom area (Alaska,1983). The relation between application rates and percolation rates and soil types is the same as those for systems designed on the basis of bottom area. Sometimes a deep trench is dug instead of a pit because the absorption area is increased with less excavation. Data on the fate of pollutants for this type of system is lacking.

Land application of wastewater effluents. The most viable year round method of land application of treated wastewater in Alaska is probably rapid infiltration/percolation because the other two types of application (irrigation and overland flow) depend on uptake from plants. This method has been developed primarily as a tertiary treatment method for nutrient removal. The method is much more effective in removing phosphorus than nitrogen (Carlson,R.R.et.al.,1982). Onsite disposal with infiltration basins was used at construction camps during construction of the pipeline in Alaska and the systems operated throughout the winter as long as a steady flow of wastewater was applied (Sletten,R.1978). Sletten conducted a study at Eielson Air Force Base, Alaska and sampled effluent applied to a rapid infiltration test basin at a rate of 15 cm per week (applied once a week). A well point was installed 2m deep and sampled during 14 weeks of the summer. Total nitrogen was reduced from about 19mg/l N to 9 mg/l N and nitrogen was considered the most limiting factor in application of this type of system. It was suggested that in cold climates the conversion of ammonia to nitrate may be inhibited during cold weather and nitrogen removal may improve. Fecal coliform removal in the same study was 95.9% (6.8x104-2.8x103 /100ml.).

In Boulder Colorado a study of rapid infiltration using primary and secondary effluent was conducted over a one year period(Carlson et.al.,1982). Nitrogen applied to the basins was converted to nitrate and discharged in the effluent. Nitrate levels in the effluent occasionally exceeded drinking water standards. The lowest nitrate concentrations in the effluent were found in the winter when nitrification was inhibited and a nitrate peak was observed in the spring when nitrification increased. Fecal Coliform removal was >96%, however concentrations in the effluent were greater than 600 /100ml. Treatment of primary effluent was found to be as effective as treatment of secondary effluent.

Pit Toilets. Horizontal separation for pit toilets or pirvies from surface waters or water supplys is 100ft. and four feet separation is required from the bottom of the pit to the highest groundwater table level (ADEC,1983). Indications of groundwater pollution by inundated privies has been documented (Hagedorn,C.L. 1983).

CONCLUSIONS

Infectious bacteria, viruses and nitrate nitrogen are the most important potential pollutants of groundwater from onsite disposal. Removal of infectious organisms is primarily dependent on passage through an adequate zone of unsaturated soil. Nitrate can accumulate in shallow groundwater tables in populated areas.

Design of onsite disposal systems is extremely site specific. It is very important to do a thorough site investigation to evaluate restrictive conditions. The primary objective in designing the soil absorption system is to allow an adequate zone of unsaturated soil. Under nonrestrictive conditions, systems will provide adequate treatment if installed and maintained properly.

Further study is needed to verify that desired removal rates are provided under unique conditions found in Alaska. Specific areas of research needed are:

Establishing the typical temperature ranges of systems throughout the year.

Measuring the survival of pathogens at low temperatures under different conditions.

Observing the transformation of various nitrogen forms in the soil.

Establishing the occurance and development time of the clogging layer in various soils.

Determining if application rates based on the side wall area of leaching pits gives desired results.

Determining the effects of deep burial and insulated lines.

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EFFECTS OF VEGETATION REMOVAL IN AN ALASKAN SUBARCTIC WATERSHED: PREIMPACT BENTHIC INVERTEBRATE STUDIES

by Mark W. Oswood[1], Charles W. Slaughter[2], Jerry W. Hilgert[3]

ABSTRACT

This study reports preimpact (baseline) studies of an Alaskan subarctic stream, conducted prior to removal of riparian vegetation. The study stream is Little Poker Creek, a small (first order) stream located in taiga forest at the Caribou-Poker Creeks Research Watershed, near Fairbanks, Alaska. Little Poker Creek was characterized by extremely cold water temperatures (summer maximum = 4.5°C), lengthy ice cover, and yearly discharge patterns showing maximum discharge periods at spring runoff and during summer storms. Benthic invertebrates were dominated by Diptera (esp. Chironomidae) followed by Ephemeroptera and Plecoptera. Trichoptera and other taxa of lotic insects were rare or absent. Collector-gatherers were the dominant functional group, followed by shredders. Filter-feeders, grazers and predators were uncommon. Moss-covered substrates supported by far the highest densities of organisms and sand the fewest. Habitat preferences differed considerably among taxa, suggesting that any changes in stream substrates caused by vegetation removal would cause changes in both abundance and community structure of benthic invertebrates.

INTRODUCTION

Need For Study

The subarctic taiga environment of interior Alaska (between the Alaska Range on the south and the Brooks Range on the north) is among the least studied forest regions of the United States. Interior Alaska is a region of discontinuous permafrost and extensive forest interspersed with low-lying wetlands and above-treeline alpine tundra. This region has the potential for vastly accelerated development and exploitation, with conflicting development pressures already evidenced by burgeoning population and volatile land ownership issues. One indicator of this increase is the exponential rise in issuance of "personal use" and commercial firewood permits issued by Alaska Division of Forestry. In the immediate vicinity of Fairbanks, issuance has risen by 64% to over 20,000 cords annually over the past seven years.

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Such intensive wood harvest may have deleterious effects on the landscape and on streams which drain that landscape. This latter possibility is implicit in the 1978 Alaska Forest Practices Act, in which regulation of timber harvest and forest management practices is based in large part on surmised consequences on water quality. A survey of water quality problems in relation to timber harvesting (URS Company/Environaid, 1977), prepared for the state of Alaska in response to Section 208, PL 92-500, stresses (1) the very limited amount of information available concerning interior Alaska environments and existing water quality relationships, (2) the limited but growing role of forest harvesting in subarctic interior Alaska, (3) the low level of supervision or regulation currently applied to forest harvesting in the region, (4) the probable importance of temporary and permanent roads, including skid trails, and stream crossings in producing increased sediment loading in streams, and (5) the need for research on the entire question of timber harvest/water quality relationships in interior Alaska.

Forestry/Stream Interactions

Forest harvest (especially clearcutting) and associated activity (e.g., road building) impact watersheds and individual streams in many ways. The literature on forest harvest/stream interactions is large and will not be reviewed here. Recent bibliographies/reviews include Crow et al. (1976), Gibbons and Salo (1973), Lynch et al. (1977), and Oswood and Barber (1978). Table 1 is an extensive but not exhaustive summary of impact of forest harvest on stream ecosystems based upon these reviews and other sources too numerous to cite.

TABLE 1. Some potential changes in watersheds/stream ecosystems caused by logging.[1]

I. LOSS OF CANOPY →
   A. ↓ litter input
   B. ↑ solar radiation →
      1. ↑ maximum summer temperature
      2. ↑ diurnal variation
   C. ↓ winter minimum temperature

II. LOSS OF STREAM BANK VEGETATION →
   A. ↑ soil mass movement
   B. ↑ erosion
   C. ↓ riparian cover for fish
   D. Δs in nutrient inputs
   E. ↓ terrestrial interception and evapotranspiration of water →↑ stream flow
   F. Δs in input of terrestrial insects as fish food

TABLE 1. (continued)

III. INPUT OF SEDIMENT →
  A. effects on developing fish eggs
    1. physical damage
    2. ↓ flow of intragravel water →
      ↓ dissolved oxygen + ↓ waste removal
  B. Δs in aquatic invertebrates
  C. loss of habitat space for fish (especially small fish and/or overwintering fish)

IV. INPUT OF LARGE DEBRIS
  A. potential benefits as cover for fish
  B. potential barriers to movement
  C. potential problems with biological oxygen demand
  D. potential ↑ in ecosystem retention of nutrients and energy

V. ROAD BUILDING AND OTHER LOGGING ASSOCIATED ACTIVITIES →
  A. heavy equipment and yarding across stream →
    erosion of lower bank
  B. roads as sediment source
  C. culvert construction → impassable barriers to movement of fry

[1] symbols as follows: ↑=increases, ↓=decreases, →=leads to, Δs=changes.

The net result of timber harvest on any portion of the stream ecosystem is very difficult to predict. For example, stream primary producers (algae, mosses etc.) may be subjected to increased solar radiation, increased nutrient levels, increased discharge rates, sedimentation by inorganic sediments, and change in grazing pressure by invertebrates. At this stage, it seems most appropriate to examine effects in terms of critical outcome variables (e.g., community structure of benthic invertebrates) which integrate these conflicting interactions.

METHODS

Study Site

Our research was conducted in the Caribou-Poker Creeks Research Watershed (CPCRW), a 104 km^2 Experimental Ecological Reserve located 45 km north of Fairbanks, Alaska. The research watershed is comprised of two primary stream systems, Caribou Creek and Poker Creek, whose joined flow is tributary to the Chatanika River. Permafrost is a dominating environmental feature, occurring on north-aspect slopes and in virtually all valleys. Climate is continental and subarctic; annual precipitation ranges from 30 to 70 cm per year, with perhaps half received as snow. The seasonal snowpack commonly remains present for six to seven months (October through April). Streams continue to flow through winter, under an ice cover of 30 to 300+ cm (in areas of severe aufeis formation).

The specific site for this research is in the Little Poker Creek (C-4) drainage of CPCRW. The stream reach is a slightly meandering, alternating pool-and-riffle channel approximately 1-2 m wide in a south-trending valley. Riparian vegetation is dominated by an overstory of black spruce and occasional larch, aspen and cottonwood. Willow, alder and dwarf birch dominate the immediate steamside vegetation, with a variable shrub understory.

Approach

We report here on Phase 1 of the research (begun in 1982) which involved physical, chemical and biological characterization of three study sections: (1) a 160 m long reach within an area scheduled for vegetation removal in early winter 1984 (termed the "cut" reach), (2) a 100 m long section immediately upstream of the "cut" reach, termed the "control" reach, and (3) a 100 m long reach downstream of the "cut" reach, termed the "recovery" reach. Phase II (1984-1986) studies at the site will concentrate on determination of the consequences of removing riparian cover to the stream biota (e.g., possible shift from allochthonous to autochthonous energy base, changes in community structure, etc.) and physical conditions (e.g., water temperature, solar radiation input to the channel, channel stability, water chemistry, etc.). Our protocol for examining effects of vegetation removal thus involves two study designs: (1) comparison of upstream, experimental (cleared) and downstream (recovery) stream reaches; and (2) "before and after" studies of all three stream reaches. This report summarizes analyses of benthic invertebrates collected from July 1982 to June 1983.

Physical-Chemical Measurements

Streamflow was monitored utilizing a Fisher-Porter 1542 water-level recorder with a fiberglass Parshall flume in the channel. Water samples (two replicates) were acquired weekly by "grab-sampling" utilizing hand-held Nalgene bottles. For chemical constituents, two 125-ml samples were filtered through Gelman microquartz glass fiber filters (0.45μm). Samples for Na, K, Ca, Mg, Fe, and Mn were acidified to pH 2 and stored in the dark at 5°C until analyzed by atomic absorption spectrophotometry (American Public Health Association, 1975). Samples for N and P were filtered in the same manner, frozen for storage, and later analyzed with a Technicon Auto-Analyzer (U.S. Environmental Protection Agency, 1976). A 500-ml sample was filtered through a tared 0.45μm Gelman microquartz glass filter to determine nonfilterable residue (American Public Health Association, 1975). Ambient water temperature, turbidity, pH, and alkalinity were measured on site with field instruments; conductivity was measured with a calibrated Beckman Solubridge meter.

Results of periphyton sampling (analysis of standing-crop biomass and accumulation rates on natural and artificial substrates) and details of physical/chemical analyses will be presented in separate publications.

Benthic Sampling

Benthic sampling was done with a Surber sampler modified as follows: (1) substitution of 350 µm mesh catch net and (2) addition of a foam rubber collar to the metal frame contacting the substrate. These modifications decreased the likelihood that early instars of insects would be lost through the net and decreased loss of specimens beneath the sampler when used on irregular substrates.

Quantitative samples were obtained in 1982 on 14 July, 4 August, 23 August, 15 September, and 6 October and in 1983 on 24 May and 6 June. On each sampling date three random samples were obtained in each study reach for a total of N=63 (3 samples per date per study reach x 3 study reaches x 7 dates). Samples were fixed in Kahle's Fluid, rinsed and transferred to 80% ethanol. Substrate material associated with each sample was classified as one of six categories: rubble (mixed cobble and gravel), gravel (rock particles up to approximately 2 cm.), bedrock (embedded rock material greater than approximately 30 cm or exposed bedrock), moss (usually on large rocks or bedrock), woody debris (greater than 2 cm in diameter), and sand. Habitat types were distributed among the 63 samples as follows: 26 rubble, 16 sand, 12 moss, 5 bedrock, 3 wood, and 1 gravel. Since sample locations were chosen randomly, these data provide a crude estimate of relative habitat abundance. However, we could not sample large masses of wood debris (encountered several times) and thus wood habitat is underestimated.

Benthic invertebrates were sorted from debris under a dissecting microscope. Identifications were made to the lowest practical taxonomic level. Organisms were counted to obtain estimates of numerical abundance and biovolumes were estimated by volumetric displacement of ethanol in a pipette. Biovolume is analogous to biomass (Cowan et al., 1983) and allows further use of specimens for gut analyses.

RESULTS

A summary of physical/chemical data are given in Table 2.

Relative abundances of benthic macroinvertebrates are given in Table 3. Three taxa (*Zapada*, *Baetis*, and especially Chironomidae) dominated while the remaining taxa were relatively rare. Figure 1 shows that Diptera were most abundant followed by Plecoptera (numerical density) or Ephemeroptera (biovolume). Trichoptera were relatively rare.

Habitat preferences for major taxa and total organisms are shown in Figure 2. Moss supported by far the highest density of organisms, followed by gravel, wood and rubble. Bedrock and especially sand supported few organisms. However, individual taxa showed striking habitat preferences. Chironomidae larvae showed a strong preference for moss while Chironomidae pupae were most abundant on wood indicating a possible habitat shift associated with pupation. Water mites (Hydracarina) were likewise associated with moss. Limnephilidae were strongly associated with gravel and Simuliidae larvae with rubble and wood.

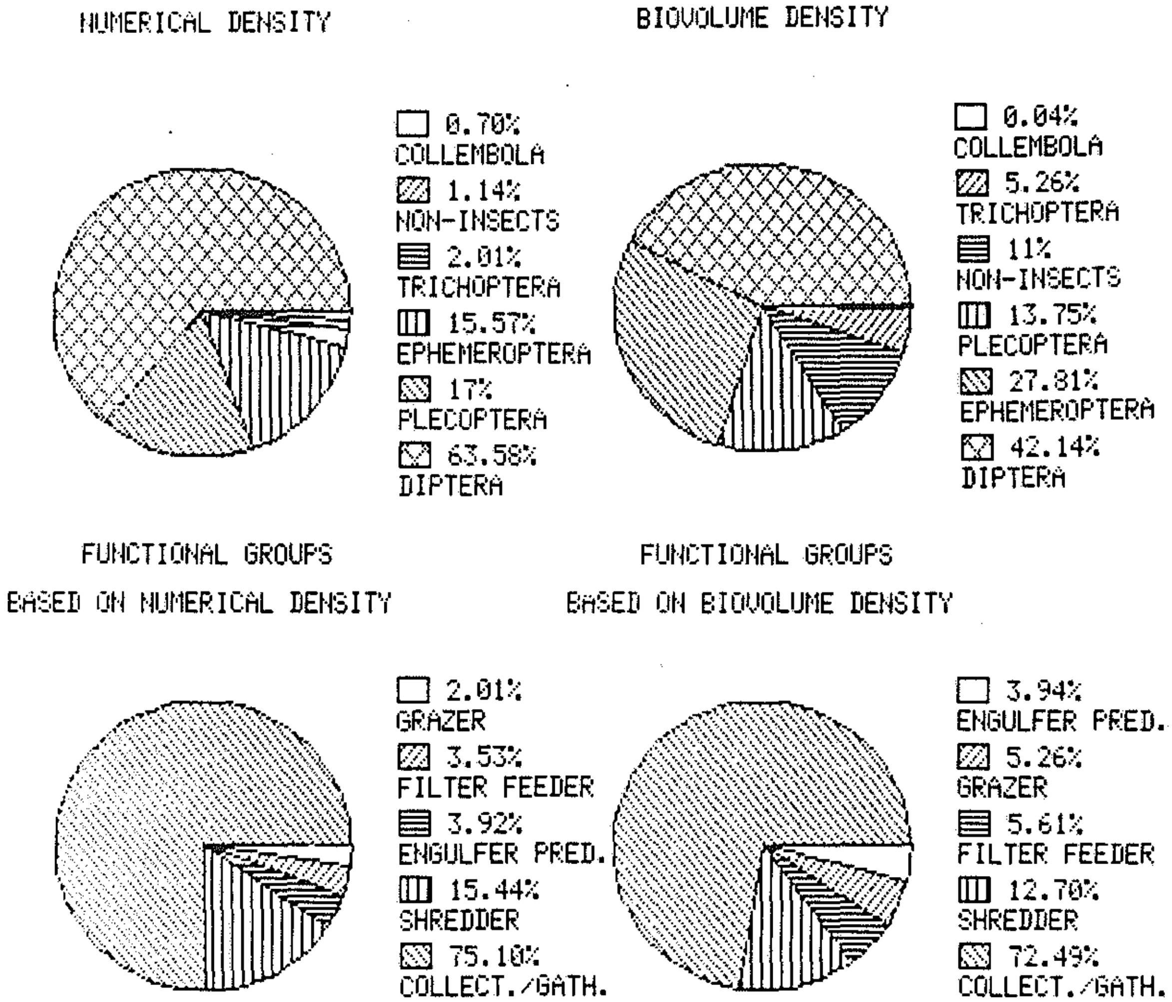

Figure 1. Taxonomic and functional group composition of benthic invertebrates, given in terms of both numerical density and biovolume. Oligochaeta were largely fragmented in samples and are included only in biovolume estimates. Functional group designations based upon Table 4.

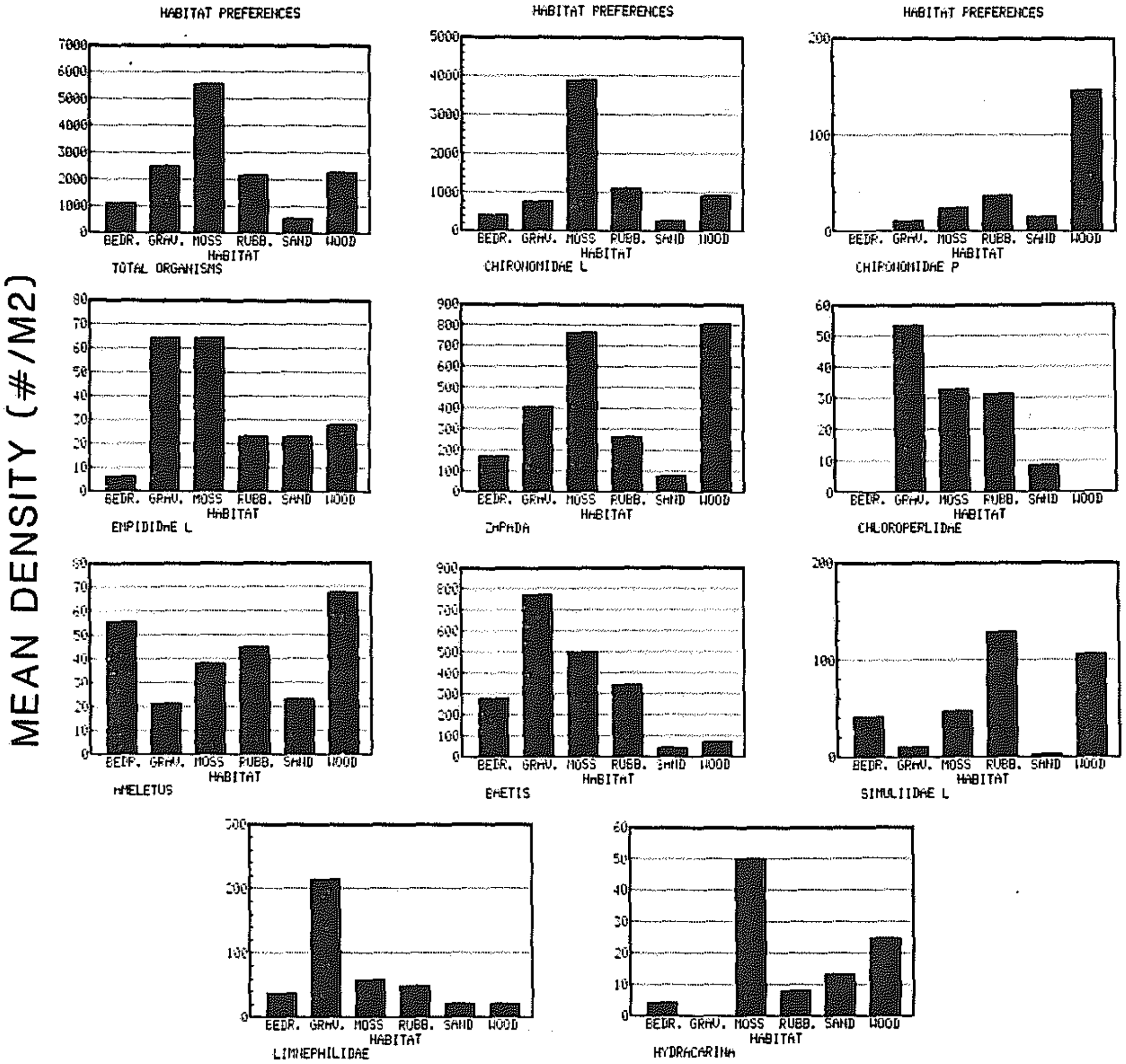

Figure 2. Habitat preferences of common taxa of benthic invertebrates. BEDR = bedrock, GRAV = gravel, RUBB = rubble, L = larvae, P = pupae.

TABLE 2. Subdrainage C-4, "Little Poker Creek" descriptive information.

Drainage Area: 11.4 km^2 Drainage Density: 0.70 $km \cdot km^{-2}$
Elevation Range: 226-686 M Proportion Underlain by Permafrost: 19%

Water Quality Characteristics, Based on Weekly Sampling During Summer 1983

Parameter	Range	Mean	Median	n
Streamflow, $l \cdot sec^{-1}$	26-236	71.8	41.5	19
Water Temperature, °C	1.0-4.5	3.4	4.0	21
pH	6.3-7.5	7.1	7.2	21
Alkalinity, $mg \cdot l^{-1}$	16-49	35	37	21
Turbidity, FTU	0.2-4.8	0.9	0.5	21
Non-filterable Residue, $mg \cdot l^{-1}$	0.1-16.6	3.2	1.6	21
Conductivity Micromhos$\cdot cm^{-2}$	42-103	75.8	78	21
Ca, $mg \cdot l^{-1}$	9.2-17.4	12.8	13.5	21
Mg, $mg \cdot l^{-1}$	1.7-2.8	2.3	2.4	21
Fe, $mg \cdot l^{-1}$	0.00-0.13	0.03	0.02	21
K, $mg \cdot l^{-1}$	0.23-1.05	0.74	0.80	21
Mn, $mg \cdot l^{-1}$	0.00-0.10	0.01	0.00	21
Na, $mg \cdot l^{-1}$	0.00-2.76	1.51	1.49	21
P (total dissolved) $\mu g \cdot l^{-1}$	0.0-35.7	6.9	3.2	18

Results of gut analyses are given in Table 4 and functional (feeding) group designations are summarized in Figure 1. Collector-gatherers dominated followed by shredders. Filter-feeders, grazers and predators were relatively uncommon.

DISCUSSION

These results are strikingly similar to other studies of small interior Alaskan streams (Brown and Oswood, unpublished data; Cowan 1983). Compared to temperate streams, Diptera are overrepresented and Plecoptera, Ephemeroptera and especially Trichoptera are underrepresented. Several orders common in temperate streams (Megaloptera, Coleoptera and Hemiptera) are absent. Each order of insects in Little Poker Creek is represented by far fewer families/genera than in most temperate streams. As is common in interior Alaskan streams, black fly larvae (Diptera:Simuliidae) appear to be the only filter-feeders.

Moss, although not abundant in Little Poker Creek, appears to be an extremely important habitat type. Maurer and Brusven (1983) similarly found insect densities 5-30 times greater in moss than in mineral substrates and suggested that insects derived from moss may contribute

TABLE 3. Ranked abundance of benthic macroinvertebrates in terms of both numerical density and biovolume. Abundance values are means of 63 samples from seven sampling periods (14 July 1982 to 23 June 1983).

Rank	Numerical Density	number per m^2	Biovolume	ml per m^2
1	Chironomidae	1297.3	Chironomidae	0.494
2	Zapada	334.8	Baetis	0.234
3	Baetis	290.5	Zapada	0.183
4	Simuliidae	78.6	Oligochaeta	0.156
5	Limnephilidae	44.7	Ameletus	0.109
6	Ameletus	40.0	Simuliidae	0.082
7	Empididae	30.9	Limnephilidae	0.077
8	Chloroperlidae	22.4	Cinygmula	0.063
9	Hydracarina	17.9	Tipulidae	0.026
10	Cinygmula	16.1	Empididae	0.014
11	Collembola	15.5	Chloroperlidae	0.009
12	Tipulidae	12.5	Perlodidae	0.007
13	Perlodidae	8.0	Hydracarina	0.003
14	Capniidae	6.8	Platyhelminthes	0.002
15	unidentified Plecoptera	6.3	Podmosta	0.002
16	Nematoda	6.1	Capniidae	0.001
17	Psychodidae	1.9	Psychodidae	0.001
18	Podmosta	1.5	Collembola	0.001
19	Platyhelminthes	1.4	Nemoura	0.000
20	Epeorus	1.4	unidentified Plecoptera	0.000
21	Dolichopodidae	0.2	Epeorus	0.000
22	Rhyacophilidae	0.2	Dolichopodidae	0.000
23	Nemoura	0.2	Rhyacophilidae	0.000

substantially to fish production. Conversely, sand and bedrock support few organisms. These data suggest that any impact (e.g. vegetation removal) which decreases abundance of moss (perhaps through deposition of sand or silt) or increases the proportion of the stream bed occupied by sand or bedrock will decrease organism abundance. Such impacts are fairly likely consequences of logging; it will be interesting to see if these predictions are borne out in the post-impact phase of this study.

ACKNOWLEDGEMENTS

We thank the following for field or laboratory assistance: Betty Brookheim, Eric Torgerson, Eugene Culp, David Kennedy, Barry Brown, and Sandra Brophy. Cathy Cowan assisted extensively with field and laboratory analyses of benthic invertebrates. We thank Will Barber, John Irons, Jackie LaPerriere, Judy Oswood, and Eric Taylor for review of the manuscript.

Table 4. Macroinvertebrate taxa encountered and results of gut analyses. Gut contents are reported as mean percentages (estimated to nearest 20%) of the total particle area. N indicates number of individuals examined. Trace amounts indicated by tr. Seasonal differences in gut contents indicated: S = summer (14 July - 25 August 1982) and A = autumn (15 September = 6 October 1982). Functional groups marked by * are based upon tables in Merritt and Cummins (1978), and by ** on Pennak 1978.

Taxon	Gut contents: Coarse plant detritus	Diatoms	Animal	Fine particulate organic material	Functional Group
Plecoptera					
Nemouridae:					
Zapada cinctipes (n=3) (A)	100	tr			shredder
Zapada spp. (n=3) (A)	100	tr			shredder
Podmosta (n=2) (S)	100	tr			shredder
Capniidae (n=2) (A)	80	20			shredder
Chloroperlidae:					
Alloperla complex (n=3) (S)			100		engulfer (predator)
Perlodidae:					
Isoperla/Clioperla (n=2) (S)			100		engulfer (predator)
(n=2) (A)		80	20		
Ephemeroptera					
Baetidae:					
Baetis (n=2) (S)		tr		100	collector-gatherer
Siphlonuridae:					
Ameletis (n=4) (S)		tr		100	collector-gatherer
(n=2) (A)		60		40	
Heptageniidae:					
Cinygmula (n=5)		tr		100	collector-gatherer
Epeorus					collector-gatherer*
Trichoptera					
Limnephilidae:					
Ecclisomyia (n=6) (A)		80		20	scraper
unidentified Limnephilidae (2) (A)	100	tr			shredder
Chyranda					?
Rhyacophilidae					engulfer (predator)*
Diptera					
Tipulidae:					
Dicranota (n=3) (A)			100		engulfer (predator)
Empididae (n=3) (A)			100		engulfer (predator)
Psychodidae					collector-gatherer*
Dolichopodidae					engulfer (predator)*
Simuliidae					filter-feeder*
Chironomidae:					
(n=30) (S)		40		60	collector-gatherer
(n=9) (A)		40	tr	60	
Collembola					collector-gatherer*
Hydracarina					engulfer predator**
Nematoda					?
Oligochaeta					collector-gatherer**
Platyhelminthes					collector-gatherer** (Zoophagous)

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WATER TREATMENT

MODELING THE INTEGRAL PRIMARY PRODUCTIVITY OF PHYTOPLANKTON IN BIG LAKE, SOUTH-CENTRAL ALASKA

by Paul F. Woods[1]

ABSTRACT

Current limnological research at Big Lake in south-central Alaska seeks to quantify temporal variations in the integral primary productivity of the phytoplankton. This goal is accomplished with a computer model, the computational format of which is described as well as the methods used to acquire the model's input data.

The following major input data are necessary: hourly solar irradiance records, coefficients for water-surface reflection and water-column extinction of irradiance, water-column profiles of temperature and chlorophyll-a concentration, and carbon assimilation rates of phytoplankton measured at various irradiances. The carbon assimilation rates are measured in a constant-light, water-bath incubator using carbon-14 as a biological tracer.

The model computes hourly rates of primary production at specified depth intervals and then integrates these over depth and time to yield a daily rate of primary production within the lake's euphotic zone. Daily rates may then be summed to determine the annual rate of primary production.

Annual rates of primary production have been extensively used to classify the trophic state of lakes throughout the world. The results of this study will thus establish the trophic state of Big Lake in relationship to these other lakes.

INTRODUCTION

Limnological research conducted since January 1983 at Big Lake in south-central Alaska (fig. 1) seeks to ascertain the lake's trophic state and its susceptibility to nutrient enrichment by sewage effluents from the numerous dwellings around the shoreline of the 12.6 square kilometer lake. The study at Big Lake is a cooperative effort between the U.S. Geological Survey and the Alaska Department of Natural Resources (Division of Geological and Geophysical Surveys) and is part of the Alaska Water Resources Evaluation (AWARE), a statewide program for water data collection and hydrologic studies (U.S. Geological Survey and Alaska Department of Natural Resources, 1984).

Nutrient supply and primary productivity have been found by numerous researchers to be strongly correlated (Schindler, 1978); hence, this

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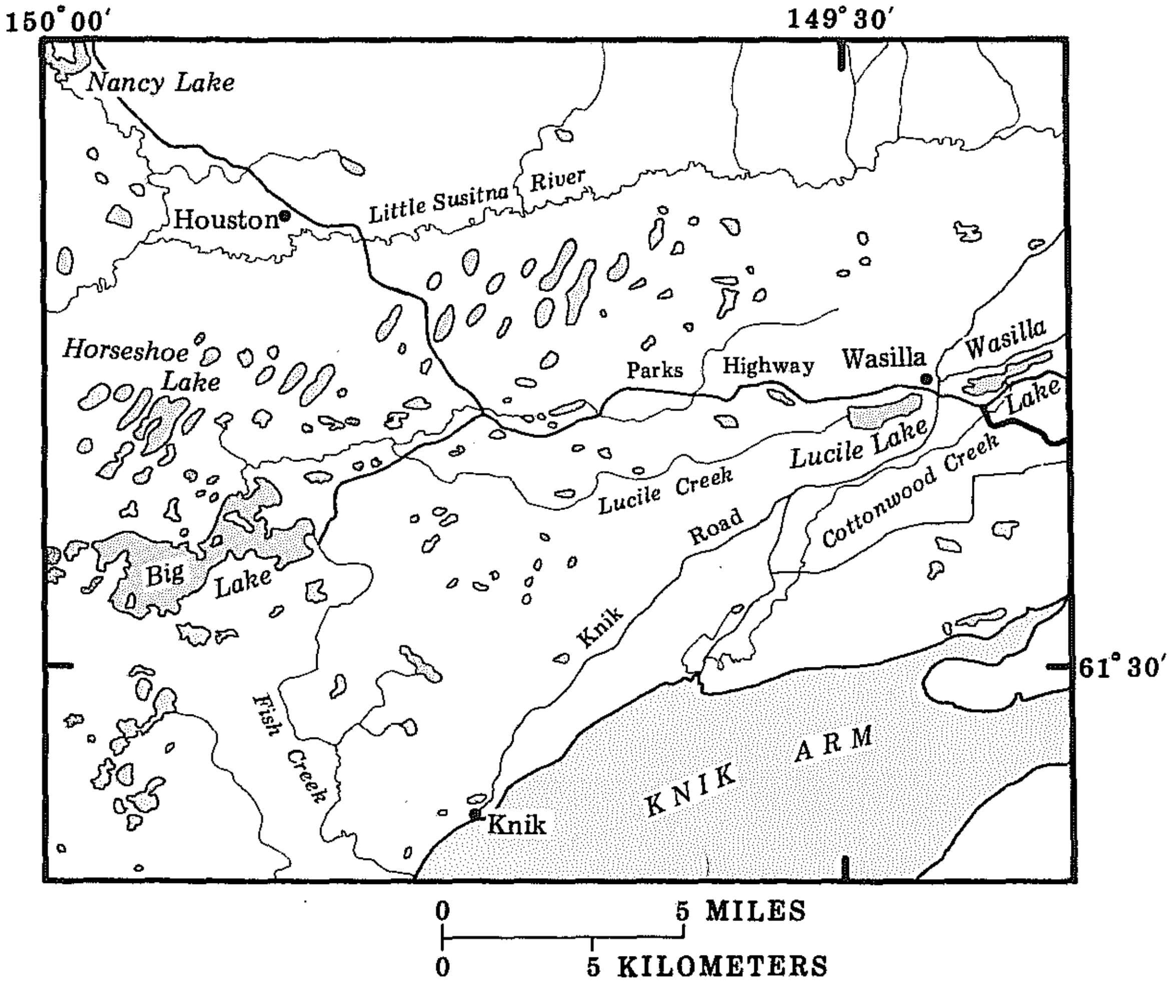

Figure 1.–Location of Big Lake in southcentral Alaska.

sampling program at Big Lake is oriented towards determining temporal variations in these two variables. Primary productivity by phytoplankton is generally the major source of new organic matter and provides the potential energy to drive lake ecosystems. As such, the trophic state of a lake may be categorized according to its integral phytoplankton primary productivity, defined as the rate at which organic matter is photosynthetically produced by phytoplankton within the water column over a specific time interval.

Numerous references outline procedures for measurement of phytoplankton primary productivity (Vollenweider, 1974; Greeson et al., 1977; Wetzel and Likens, 1979; and Harris, 1980). However, there are many differences in procedure among these references and the many others that describe studies of primary productivity. It is, therefore, imperative that published studies of primary productivity explicitly describe the procedures that were used.

The aim of this paper is to discuss the procedures we use to measure phytoplankton primary productivity at Big Lake.

MEASUREMENT OF PHYTOPLANKTON PRIMARY PRODUCTIVITY

Studies of phytoplankton primary productivity require measurements of the rate of photosynthetic fixation of organic matter by phytoplankton sampled from selected depths. The rates thus obtained are reported as the quantity fixed per cubic meter per hour. These hourly rates are then expanded into daily volumetric rates. Integration of the daily volumetric rates measured within the water column yields the quantity of organic matter fixed per day under a square meter of lake surface area. This value is termed daily areal primary production or daily integral primary production.

We measure hourly rates of phytoplankton primary production in Big Lake with the carbon-14 light and dark bottle method in conjunction with a constant-light, water-bath incubator. The results of the incubator experiments are combined with selected limnological data and continuous records of solar irradiance and are input to a computer model. The model computes daily integral primary production for each day with solar irradiance data. The final value we seek is an estimate of the annual integral primary production by phytoplankton within the lake-wide euphotic zone of Big Lake.

Limnological Data

Limnological data collection begins with water column profiles of temperature, photosynthetically active radiation (PAR), and chlorophyll-a concentration. Temperature data are used to delineate the epilimnion, metalimnion, and hypolimnion, whereas the PAR profile establishes the depth of the euphotic zone. In this study, the depth of the euphotic zone is defined as the depth at which the PAR incident upon lake surface has been reduced to 1.0 percent. Zonation of chlorophyll-a is detected in-vivo using a fluorometer equipped with a flow-through pumping system. Discrete samples for quantitative analysis of chlorophyll-a are then taken with an opaque sampler.

Temperature, PAR, and chlorophyll-a profiles are used to select the depths from which water will be taken for later use in the incubator experiments. The selected depths, between one and three, are sampled with an 8-liter opaque sampler. The samples are then transferred to darkened carboys and kept cool until use in the incubator experiments.

The profile of PAR is used to compute the extinction coefficient of the water column and the reflection coefficient of the lake's surface. The amount of PAR incident upon Big Lake has been continuously recorded since January 1983 by a solar irradiance monitor at the Big Lake Hatchery. The terrestrial PAR records and the coefficients for extinction and reflection are major input data for the primary productivity model.

Incubator Experiments

The goal of the incubator experiments is to derive the functional relationship between photosynthetic fixation of organic matter and various amounts of PAR. This is accomplished by exposing phytoplankton samples to different amounts of PAR within a five-chambered, constant-light, water-bath incubator (fig. 2). The incubator is an extensively modified version of an incubator described by Shearer (1976). The carboys filled at Big Lake are used to fill 11 light (clear) bottles and one dark (opaque) bottle for each depth sampled. Each 60-milliliter sample bottle is then inoculated with 100 microliters of radioactive tracer (carbon-14 in sodium bicarbonate solution, activity of 27 microcuries per milliliter). Two light bottles from each depth are placed in each of the incubator's five chambers. The algae in the remaining light bottle for for each depth are killed shortly after filling by injecting the sample with 250 microliters of Lugols-acetate solution. These bottles serve as zero-time blanks. Each dark bottle is incubated in the rearmost chamber and quantifies both non-photosynthetic uptake and inactive fixation of carbon-14. The PAR in each chamber is measured before and after incubation with the instrumentation used to measure PAR within Big Lake. Removable screens between the light source (a 400-watt metal halide lamp) and each chamber permit adjustment of PAR within the incubator. During the 3 to 4 hour incubation the bottles are constantly rotated to simulate water-column turbulence and prevent settling of particulates. A circulating water system allows control of the incubator's water temperature during the incubation. To avoid excessive thermal shock to the phytoplankton, we incubate samples at temperatures near those of the depths sampled.

During incubation, an aliquot from each carboy is analyzed on an infrared carbon analyzer for concentration of total inorganic carbon. Concentrations of chlorophyll-a, corrected for pheophytin, are measured fluorometrically on samples from each carboy as well as the discrete depth samples taken during the in-vivo profiling.

Immediately after incubation, the algae in the light and dark bottles are killed with an injection of Lugols-acetate and are then vacuum-filtered onto glass-fiber filters. The carbon-14 assimilated by the

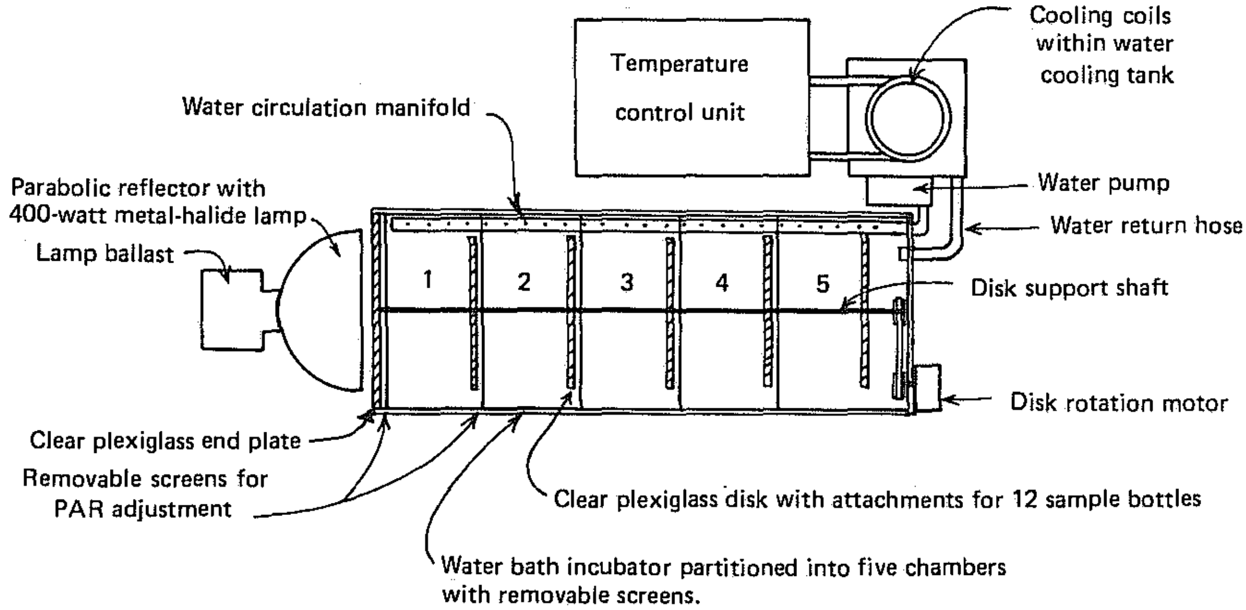

Figure 2.--Constant-light, water-bath incubator for measurement of phytoplankton primary productivity under various amounts of photosynthetically active radiation.

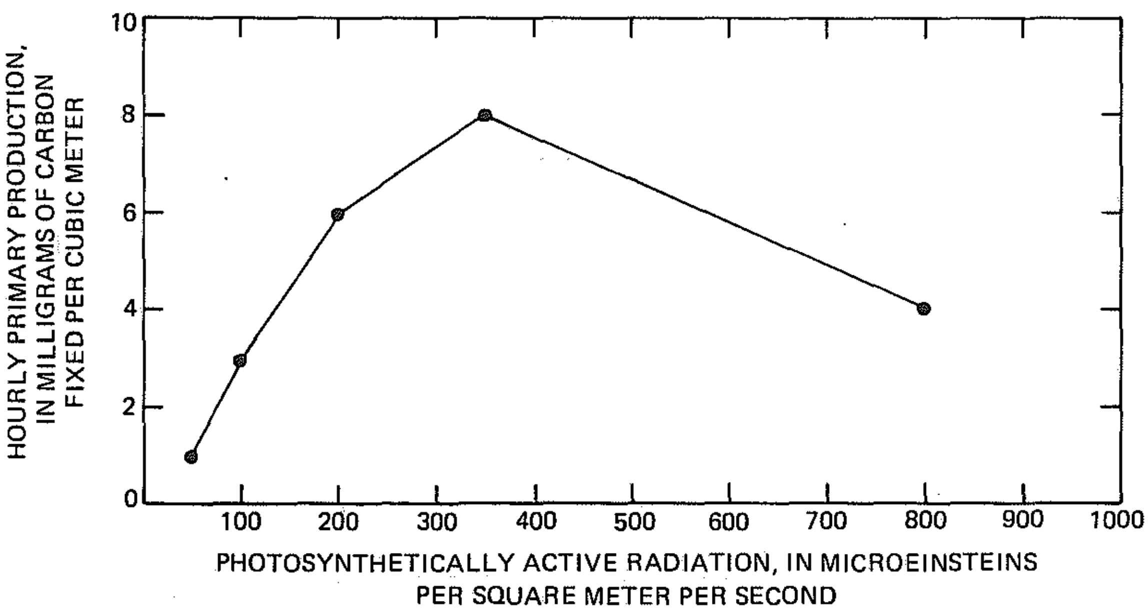

Figure 3.--Curve relating photosynthetically active radiation and hourly primary production.

phytoplankton during incubation is retained on the filters. The radioactivity on the filters is measured with a liquid scintillation spectrophotometer.

The hourly rate of primary production can then be calculated with the following equation:

$$H = \frac{(C)(D_S - D_B)\,\dfrac{V_T}{V_F}\,(I)(f)}{(D_T\ \ (T)} \tag{1}$$

where H is hourly rate of primary production, in milligrams of carbon fixed per cubic meter per hour;

C is total inorganic carbon concentration, in milligrams per liter;

D_S is disintegrations per minute of incubated sample;

D_B is disintegrations per minute of zero-time blank;

V_T is volume of sample bottle, in milliliters;

V_F is volume of sample filtered, in milliliters;

I is an isotope discrimination factor (1.06);

f is a factor (1000) to convert liters to cubic meters;

D_T is disintegrations per minute originally added to incubated sample;

T is incubation time, in hours.

The results from equation 1 for each chamber of the incubator are plotted against the PAR values in the incubator (fig. 3). These data pairs are then input to the primary productivity model.

PRIMARY PRODUCTIVITY MODEL

The data obtained from the incubator experiments, limnological sampling, and the solar irradiance monitor are input to a computer model for computation of primary productivity. An earlier version of this model was developed by Jasper et al. (1983) to study primary productivity in Kootenay Lake, British Columbia. The version being used at Big Lake is a FORTRAN program called BIOMOD.

The model computes daily integral primary production over the time interval between two sampling dates specified by the model user. Data for each sampling date must include the following: water temperature profile, chlorophyll-a profile, extinction coefficient, and a curve relating hourly primary production to PAR. The production - PAR curves must also define the sampling depths they represent and their incubation temperature. The model user also specifies the integration interval (usually one meter), the depth of integration, the reflection coefficient, and a temperature correction coefficient. Solar irradiance data, recorded at one hour intervals, are input for each day to be computed.

The temperature and chlorophyll data for both sampling dates are linearly interpolated to fill in data for those depths not sampled. These depth profiles are then used to linearly interpolate values of temperature and chlorophyll for days between the two sampling dates.

The PAR values at each depth on both sampling dates are computed as follows:

$$PAR_z = (1 - R)(PAR_s)(e^{-nz}) \qquad (2)$$

where PAR_z is photosynthetically active radiation, in microeinsteins per square meter per second, at a specified depth;
- z is depth, in meters;
- R is reflection coefficient;
- PAR_s is photosynthetically active radiation, in microeinsteins per square meter per second, measured by the solar irradiance monitor;
- e is base of natural logarithms; and
- n is extinction coefficient.

The PAR_z values between the two sampling dates are computed in a similar manner; however, the extinction coefficient for each day is interpolated from the extinction coefficients measured on the two sampling dates.

The curves of hourly primary production and PAR for both sampling dates are normalized with respect to their associated chlorophyll-a concentrations. The resultant values are then interpolated over the depth to be integrated for both sampling dates. The two profiles of chlorophyll-normalized productivities are then interpolated over the days between the two sampling dates.

The model now finds a PAR value for each depth on each day and multiplies each by its appropriate chlorophyll-normalized hourly primary production. These values are then multiplied by their associated chlorophyll-a concentration to achieve hourly rates of primary productivity per cubic meter for each depth on each day of the specified interval. Equation 3 further modifies these values by correcting them for differences between in-situ and incubator temperatures:

$$H = (P)(Q_{10})^{(T_Z-T_I)/10} \qquad (3)$$

where H is hourly primary production, in milligrams of carbon fixed per cubic meter per hour;
- P is non-temperature corrected hourly primary production, in milligrams of carbon fixed per meter per hour;
- Q_{10} is temperature correction coefficient;
- T_z is in-situ water temperature, in degrees Celsius; and
- T_I is incubator water temperature, in degrees Celsius.

The temperature-corrected values of hourly primary production are then summed over depth and time to yield daily integral primary production.

Expansion to Annual Lake-Wide Values

The daily integral primary production values generated by the model are summed over a calendar year to obtain the annual integral primary production of the sampling station under consideration. Each station's summation represents the annual primary production within the water column under a square meter of lake surface.

To obtain an annual lake-wide value one must first apportion the lake surface area into those regions represented by the primary productivity sampling stations. We have two such stations on Big Lake; one in the east basin, the other in the west basin. The annual lake-wide primary production of Big Lake can then be calculated as follows:

$$L = (P_E \times S_E) + (P_W \times S_W) \qquad (4)$$

where L is annual lake-wide primary production, in milligrams of carbon fixed per year;

P_E is annual integral primary production measured in east basin of Big Lake, in milligrams of carbon fixed per square meter per year;

S_E is lake surface area of east basin of Big Lake, in square meters;

P_W is annual integral primary production measured in west basin of Big Lake, in milligrams of carbon fixed per square meter per year;

S_W is lake surface area of west basin of Big Lake, in square meters.

The primary productivity studies at Big Lake are not yet completed; thus we do not yet have modeled values for daily integral primary production. When this project is completed we will have quantified annual integral primary production at Big Lake for 1983 and 1984.

TROPHIC STATE CLASSIFICATION

Annual production of organic matter, as carbon, varies widely among lakes and has thus been used as a criterion for classifying lake trophic state. Three ranges of annual primary production, expressed in grams of carbon fixed per square meter per year, were cited by Welch (1980) as indicative of the following three trophic states in lakes: oligotrophic, 7 to 25; mesotrophic, 25 to 75; and eutrophic, 75 to 700.

Numerous measurements of daily integral primary production have been reported for Alaskan lakes (Goldman, 1960; Barsdate and Alexander, 1971; and Koenings and Kyle, 1982); however, very few studies of annual integral primary production and trophic state have been done in Alaska. One of the more detailed studies of the latter type was reported by LaPerriere et al. (1977) for Harding Lake in central Alaska (64°25' N, 146°50' W). Phytoplankton primary productivity was measured with the carbon-14 light and dark bottle method using 24-hour in-situ incubations. These measurements resulted in an annual integral primary production of 47.8 grams of carbon per square meter per year for Harding Lake. Thus, Harding Lake was mesotrophic according to the criteria of Welch (1980).

This study at Big Lake includes measurements of hourly, daily, and annual rates of integral primary production. We will thus be able to compare its primary productivity to that of other Alaskan lakes as well as lakes throughout the world.

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DEVELOPMENT PRESSURES ON ANCHORAGE FLOOD PLAINS

by Kenneth E. Hitch, P.E.[1]

ABSTRACT

The growth in the Municipality of Anchorage has been staggering, and most good, dry land has been developed. This has resulted in pressure to encroach on the flood plains of Campbell, Little Campbell, Chester, Ship, and Fish Creeks. Problems with insurance and liability have resulted from changed flood plains. The need to identify flood plains in the Anchorage bowl was established in the 1960's and maps were printed in 1968. It was soon decided that identifying the flood plain was not the total answer. It warned people of flood dangers but did not recommend against development in the flood plain. Therefore in 1972, a floodway was added to the maps to identify an area that should not be developed. The Borough of Anchorage, recognizing the need for control over flood plains and wanting flood insurance to be available to its residents, passed an ordinance in 1971 to prevent development in floodways and make flood insurance available to residents. Since that time, developers have been encroaching on Anchorage flood plains with and without approval of the municipality. In 1983, these developers nearly caused the elimination of flood insurance coverage in Anchorage when inspection revealed violations of the ordinance. Anchorage was placed on probation under the National Flood Insurance Program. The municipality is trying to correct the situation, but problems still exist.

INTRODUCTION

The battle between development pressures and conservation of flood plains plays an important role in the lives of many Alaskans and particularly the citizens of Anchorage, Alaska's largest city. A delicate balance must be attained. This paper discusses the issues involved and provides guidance to decision makers and developers to avoid legal problems.

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ANALYSIS OF THE PROBLEM

History of Flood Hazard Program

The need to identify flood plains in the Anchorage bowl was recognized in the 1960's. Maps with flood plain boundaries were published in 1968, the same year the National Flood Insurance Act was passed. The National Flood Insurance Program (NFIP) is a Federal program enabling property owners to purchase flood insurance. Such insurance is designed to reduce the escalating costs of property damage caused by floods. The program is based on an agreement between local communities and the Federal government: If a community will implement programs to reduce future flood risks, the Federal government will make flood insurance available as a financial protection against flood losses which do occur. On October 12, 1971, the Greater Anchorage Area Borough (now merged with the Municipality of Anchorage) enacted Ordinance #122-70 to comply with NFIP. Flood insurance soon became available to residents and businesses of Anchorage. The first maps did not include all streams in Anchorage and were limited in detail, so the Federal Insurance Administration (FIA) at the municipality's request, directed the Corps of Engineers to do a comprehensive flood plain study. As a result of this study, Flood Hazard Boundary Maps (FHBM's) were published in March 1979. While this study was nearing completion, the municipality put into effect on November 22, 1977 Title 21 of the Anchorage Municipal Code, which further established floodplain regulations. The next few years saw rapid development in Anchorage, necessitating revisions to the FHBM's. In July 1983 the Federal Emergency Management Agency (FEMA), formerly FIA, directed the Corps of Engineers, Alaska District, to perform a re-study of Little Campbell Creek, Chester Creek, Fish Creek, Eagle River, and Fire Creek. The results of this study are scheduled to be submitted to FEMA for review in January 1985. In the course of the study it was discovered that these streams have in some cases been built over, relocated, and even blocked under the guise of development. For any of this to happen without the approval of both the municipality and FEMA is a violation of the Municipal Flood Plain Regulations. Chapter 21.60 of Title 21 prohibits any development, including excavation or landfill, without a special Flood Hazard Permit. Such permits are granted only under certain conditions. Development has been occurring in Anchorage without consideration of the city's flood plains, which may result in severe consequences. These will be explained in detail later in this report.

Currently there are only 97 flood insurance policies in effect in Anchorage, but it is estimated that there are several hundred structures actually in the flood plain and more than 1,000 people residing in the flood plain.

Past Flooding in Municipality

Records of floods in Anchorage are very meager. National Weather Service records, newspaper accounts, and interviews with old-time residents along streams reveal the following record of maximum flood events:

Anchorage Flood History

Stream	Date of Flood	Estimated Flood Recurrence Interval
Ship Creek	June 1949	50-year
Campbell Creek	June 1949	100-year
Chester Creek	Apr 1963	5-year
Rabbit Creek	June 1964	100-year
Eagle River	Sept 1967	20-year
Glacier Creek	Sept 1967	20-year
Ship Creek	Aug 1971	20-year
Campbell Creek	Aug 1971	1.7-year
Chester Creek	Aug 1971	1.1-year
Peters Creek	Aug 1971	50-year
Meadow Creek	Aug 1971	5-year

As indicated above, there has not been any significant flooding in over 13 years. This has led to a rather laissez-faire attitude in Anchorage concerning flood plains, especially considering that the new development in flood plains has been since the last major flood, and a lot of new unwary people have moved into Anchorage since 1971.

The above record clearly establishes the fact that it can and in fact has flooded in Anchorage, but a few newspaper headlines will make it more vivid: "Seward Highway cut by flood. Autos stranded at Rabbit Creek. State Highway Department crews fought today to control raging flood waters which carried out the road where the Seward Highway crosses Rabbit Creek. Rushing flood waters from Rabbit Creek backed up 40 feet deep behind the Seward Highway earlier today."1/ "Community homes hit by flooding streams. Property loss from rampage unknown. Rain-soaked ground could no longer absorb last weekend's heavy rainfall, shunting millions of gallons of water from the mountainsides into waterways. Streams usually nothing more than meandering brooks were transformed into raging torrents. At about 11 a.m. Sunday, Little Peters Creek rose suddenly, jumping its channel. In the yard of Mr. and Mrs. O.C. Hickling, the raging stream slammed directly into their home, making their driveway its new channel.

1/ Anchorage Daily Times, June 23, 1964.

Later Sunday evening, another stream eight miles away started its destruction. Meadow Creek, a beautiful, peaceful stream under usual circumstances, became a tearing, chewing monster. It took away a section of yard and patio of the Vanover residence."2/ "The Rabbit Creek flood forced evacuation of five families living on Rabbit Creek Road. 'I understand our home is on an island now, but I don't know of any actual damage yet,' Mrs. Howard said today. 'We waded in yesterday and saved a few things in the house. The main damage is to the garage and the foundation of the house,' said Valade. Mr. and Mrs. Mahoney and their four children moved back into their mud-filled home Tuesday night. Mrs. Mahoney reported that parts of the house had as much as a foot of mud."3/

A little closer to downtown Anchorage was the flooding of Chester Creek. Residents recalled winter and early spring flooding of many homes in the Homesite Park, DeBarr Vista and Nunaka Valley areas. The Corps of Engineers furnished sandbags to protect homes. The school in Nunaka Valley has been closed and its well contaminated due to flooding.

So Anchorage floods are reality.

Record Growth

Pressures for development in flood plains are fed by the fact that Anchorage is the fastest growing metropolis in America. The population has grown 33 percent in the past three years. In 1980, the city issued 1,070 building permits worth nearly $155 million. In the construction boom years of 1983, there were 6,572 permits issued for a value exceeding $1 billion - more than for Seattle, Portland and Honolulu combined.4/ The municipal staff has not expanded at the same rate, so it is understandable that developers have been able to get away with some violations.

Flood Plain Management

Flood plain management refers to an overall community program of corrective and preventive measures for reducing flood damage. These measures take a variety of forms: zoning, subdivision or building requirements, or special-purpose flood plain ordinances. The key item to managing a flood plain is the floodway. The floodway includes the channel of a stream and the adjacent flood plain that must be reserved in order to discharge the base flood, which national standards define as the 100-year flood.

2/ Chugiak-Eagle River Star, August 12, 1971.
3/ Anchorage Daily Times, June 24, 1964.

4/ Anchorage Today, Special Issue, Fall 1984.

FEMA requires the community to designate a part of the flood plain as a "regulatory floodway" to avoid the possiblity of significantly increasing upstream flood elevations. This regulatory floodway, when preserved, will not cause a cumulative increase in the water surface elevation of the base flood of more than one foot at any point. Within this designated floodway a community must prohibit development that would cause any additional rise in base flood elevations. This is what many developers have ignored. If development is planned in or near a flood plain, it is the responsibility of the developer to prove that his proposal will not cause any additional rise in flood elevations. If the proposal includes any realinement of the stream itself, the developer is required to perform the hydraulic engineering that would create the new flood plain with floodway. The developer must gain approval from the municipality as well as FEMA prior to any construction. Until FEMA approves a change to the flood plain and issues a map amendment, the existing map is official. Lending institutions will not provide financing for construction in the official floodway, even though it be vacated.

Wetlands

There is a relationship between flood plains and wetlands, but much confusion exists because their definitions are different and the regulating authority is different. The term "wetlands" describes several different kinds of land that may perform similar functions. They include swamps, bogs, marshes, wet tundra, and other lands that are periodically or permanently covered by water or that suppport plants (such as sedges, alders, and black spruce) which often grow in wet areas. The U.S. Congress has determined the importance of preserving wetlands as habitat for fish, animals, and birds. But wetlands have another function important to Anchorage residents - they can absorb large amounts of water like a sponge and act as natural flood control systems for streams. Wetlands slow the rate of water flow over land (runoff) during periods of rainfall, allowing water that would otherwise quickly flow into streams to be released slowly into the ground or stream. Wetlands, then, serve as natural storm buffers, protecting human life and property. They also prevent erosion and filter pollutants out of water. Thus, wetlands are important to flood plain management. Congress directed the Corps of Engineers to protect wetlands through the issue of permits. These permits are different from flood hazard permits, which the municipality requires to control development in flood plains and thereby reduce the threat to life and property. The Corps of Engineers acts strictly as a technical consultant and has no authority over flood hazard permits.

Liabilities

Who is liable for causing increased drainage problems or flooding on someone else's land? This is not an easy question. The answer varies as state laws vary and as court decisions are rendered. However, courts have held private property owners, subdividers, builders, lending institutions, and governmental bodies liable in certain cases of flood and drainage damage. In the Flood Insurance Program, if a community, developer, builder, or other responsible party acts unreasonably or fails to take action required by law, and flooding occurs as a result, the responsible party may be held liable for damage. Over the years, FEMA has paid millions of dollars in flood insurance claims. There are indications that many of these claims arose due to the negligent actions or inactions of third parties. FEMA, as a result, has begun to pursue its legal remedies under a theory of subrogation in an attempt to recover these payments from responsible third parties. In United States v. Parish of Jefferson, et. al., an ongoing case arising in suburban New Orleans which is the major test for many of FEMA's claims, the local government, the developer, and an engineering and surveying firm are being sued for over $120 million for claims the Government paid.

RECOMMENDATIONS

Besides being held liable for damages caused by unapproved development in flood plains, developers can expect substantial delays and possibly orders to return the property to its original state. To avoid any problems, the following recommendations are made:

1) Municipal staff should insure that strong policies exist so that personnel turnover will not allow unauthorized development to occur.

2) Municipal staff should tighten permit procedures and take enforcement actions against violators.

3) Developers should plan for allowance of floodways and utilize greenbelts as a positive selling feature.

4) Developers should start early and obtain the Municipal Flood Plain Permit and the Corps of Engineers Wetland Permit before they start construction.

5) Engineering firms should inform their clients of flood plain requirements and recommend alternatives to stream relocations. If stream relocation is the only alternative, engineers should obtain correct design flows and insure against development causing adjacent flood problems. The Corps of Engineers has the hydraulic data necessary and will provide assistance.

6) All firms and individuals involved with flood plains should review the draft Flood Insurance Study for Anchorage when it is submitted for public review in 1985 or 1986 to insure its accuracy and become familiar with Anchorage flood plains.

7) Individual property owners near flood plains should not place fill or structures in the flood plain without ascertaining whether permits are required and whether the action will affect other adjacent property owners.

CONCLUSION

Flood plains are an important resource to the community of Anchorage. They are becoming more important as development closes in on them. Asphalt is replacing sod, and existing streams will have to carry more water because it cannot be absorbed by the ground. Unless development is halted at some point with greenbelts and floodways preserved, an increasing number of Anchorage residents will suffer flood damage, and engineers and developers are going to be held liable.

IS A WATER USE INFORMATION PROGRAM USEFUL TO ALASKA?

by Leslie D. Patrick[1]

ABSTRACT

Decision-makers need adequate information on usage of water to resolve critical water issues such as environmental impact, energy development, resources allocation, and water quality. Data on different aspects of water use are available from various local, state, and federal agencies, but information for many regions and types of water use is either scattered or largely nonexistent. The information which is available ranges in format from hearsay estimates to computer-stored meter readings.

A water-use information program could compile existing data and store them in a single data base. Such a program could provide for collection of new data, and the development of innovative approaches for water-use data acquisition and analysis. It could define the withdrawal, transfer, and return cycle of water used in Alaska. It could provide scientists, engineers, managers, planners, and others with a foundation from which to make sound decisions and evaluations on water development projects. Such a program would complement existing water-quality and availability information.

INTRODUCTION

Alaska is a water abundant state with a total population smaller than many major cities. Obviously, there is plenty of water to go around. So who cares how much water is being used? Developers requesting a water right for a multi-family development who are told there isn't enough water, scientists who need to decide whether industrial water withdrawals are affecting lake levels, planners who need to project future water demands are just a few.

Many states with a history of water problems have developed standard procedures to collect usage data. Even so, national compilations show many discrepancies in definitions. Consumptive use figures for septic systems range from 0 to 100 percent. Some use estimates conclude 130 gal/d per person on a public supply system, others report it as 130 gal/d per household; much of the confusion depends on whether industry is included in the figure.

With the recognition of the finite nature of water resources, and an increased awareness of possible mismanagement of water supplies, there is a need for current, readily accessible water-use data. Because

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Alaska is an appropriation state, managers must know how much water is reasonable for a particular use. Managers must know how much water is currently removed from the hydrologic system, where it is returned, and if it is returned - is it reusable? This is information on the actual amount of water used, and not the amount permitted for use.

THE NATIONAL WATER USE PROGRAM

In 1978 the U.S. Geological Survey began developing a program which would meet the national need for a single source of uniform information on water use. The National Water-Use Information Program was designed to collect, store, and disseminate water-use information to account for the water used throughout the United States. It was designed to provide the information necessary to update and project national water requirements. The data stored in the National Water Use Data System (NWUDS) data base is aggregated by county and by hydrologic unit. Each aggregation is further divided into a source or usage data base. The national information is stored in a format readily accessible and useful in water-resource assessments grouped by hydrologic unit, county codes, or larger combinations of those divisions. The information from this program complements long-term Geological Survey data on the availability and quality of the Nation's water resources, and is used once every 5 years for the national water use summaries.

Currently, the national data base is not useable for many purposes because there are so few data in it. Even when totally functional, the national data base will not supply data sufficient for the states to manage their water resources. Individual states require a more site-specific data base than that provided by the national aggregations. Realizing this, the Water Use Program was developed as a Federal-State cooperative program, in which the real development comes from each state. It was envisioned that each agency would benefit from such a cooperative program -- the national summaries would be more consistent and up-to-date, and the states would acquire the information necessary to realistically quantify and track water usage. Thus, although the standards that provide for a nationally consistent and comprehensive program are the responsibility of the Geological Survey, the collection, analysis, and aggregation of data stored in the national data base for each state are the responsibility of each state's cooperative program.

The National Water-Use Information Program has identified the following 12 major categories of water use: agricultural non-irrigation, commercial, domestic, industrial, irrigation, mining, public supplies, sewage treatment; and fossil-fuel, geothermal, hydroelectric, and nuclear power generaton. Each state is expected to routinely collect information for each category and submit it to the national data system. In addition, the states may collect other data depending on their specific needs.

ALASKA'S DATA

Specific numbers must exist before they can be aggregated. Some data on different aspects of water use are available in Alaska from various local, state, and federal agencies. However, the information for many regions and types of water users is either scattered or nonexistent.

When available, the data vary in accuracy, reliability, and format -- some estimated, some metered, some computerized, some not. The format may be designed for a particular use and not applicable to other studies. For example, the Department of Agriculture reports information on irrigated acreage, but doesn't identify amount of water by source type. The amount of water withdrawn by a public utility may be known by that utility, however information from each utility is in a different format and detail. Private homes may not be metered; the number of connections may be available, but the amount of water going to each connection is not. For basin-wide management, information on withdrawals, system losses, and return points are required.

ALASKA'S WATER USE PROGRAM

Interagency meetings were held in 1978 to cultivate interest in a cooperative water-use information program for Alaska. Because of its role in regulating water rights and other water laws, the Division of Land and Water Management showed the most interest in the program and became the lead state agency for program development. The main thrust of the program was to computerize the water rights, dam inventory, well log, and water-use files. These four data bases were to become a subsystem of the Department of Natural Resource's Alaska Land and Resource System.

The water-use data base categorizes water as ground water, surface water, transfer water, or injection water. Although designed to accept each distinct withdrawal, return, delivery, or release point, it can be used to accept grouped data if so desired. Annual, monthly, metered, or estimated data can be coded. The ability to identify what entity collects or reports the information, and to qualify its accuracy is included. The data are stored by standardized industrial classification code on a site-specific basis. Therefore, the data can be aggregated at whatever level is desirable. Provisions have been made to restrict distribution of data when confidentiality is requested. Software to summarize site-specific data for input to NWUDS has been developed. A users manual has been written to explain the online data entry procedures.

The water-use program plans to compile existing data, collect new data, and store them in this data base. It plans to develop innovative approaches to water-use data acquisition and analysis. The program proposes to develop methods to statistically estimate water use, and to define the withdrawal, transfer, and return cycle of water used in Alaska, at least for the major metropolitan areas. The information can be used for:

Water budget studies.

Projecting future water demands.

Quantifying uses in order to allocate water resources.

Water Demand Modeling - which aids in planning the design, extensions, and rate structuring of water systems.

Determining the periodicity of water withdrawal and return, by use.

Evaluating the adequacy of currently developed water resources and planning for new water supply development.

Calculating water loss due to system leakage.

Providing data for industrial plant siting and suitable supply development.

Maintaining consistency of information released to the public and thus minimizing duplication of effort.

Determining present water uses and assisting planners and managers in projecting future water demands.

In 1978 developing a site-specific water-use data base seemed to be the best choice for program development. None of the existing data files, machine or office, were comprehensive enough to allow state-, basin-, or even city-wide water-use analysis. It is possible that other agencies have since developed more thorough data bases for their own information. However, compiling the information into a single statewide resource data base which will complement existing water-quality and availablity information, and will provide scientists, engineers, managers, planners, and others with a foundation from which to make sound decisions and evaluations on water development projects, continues to be a goal of the water use program.

Compiling the existing and newly collected data into a central computerized repository would facilitate its use. For example, computer statistics and graphics software could be used to readily display the information. The data could be used as direct input to ground-water models. It could be used in conjunction with other data bases and utilize automated mapping systems as an aid to resource development. The information would be machine transferable, rather than having to be photocopied and/or hand copied. Users would no longer have to inventory all agencies each time a study requiring use information was done.

CONCLUSION

If a state wants to manage its resource, match availability with present and/or expected use, or legally justify why or why not a certain amount of water constitutes a reasonable use, there is a critical need for water-use data. In today's information-based society, a statewide computerized water-resource data base having the capabilities of storing, retrieving, synthesizing, and displaying such information could greatly benefit potential users. A data bank of how much and where water is withdrawn or returned to the natural environment, and how much water is transferred between facilities has many applications. The resulting data could be shared by all users.